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SUBMARINE TELEGRAPHY

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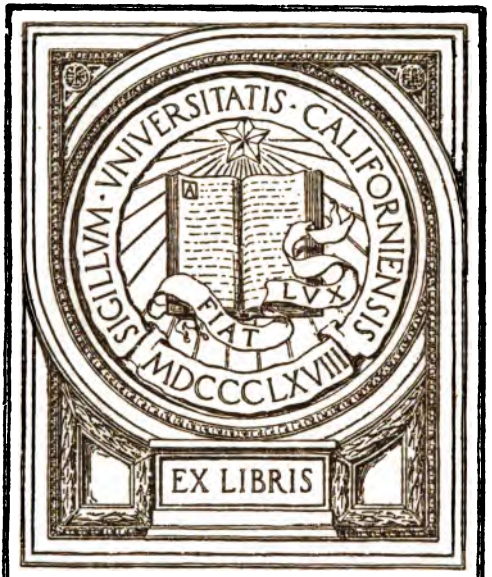

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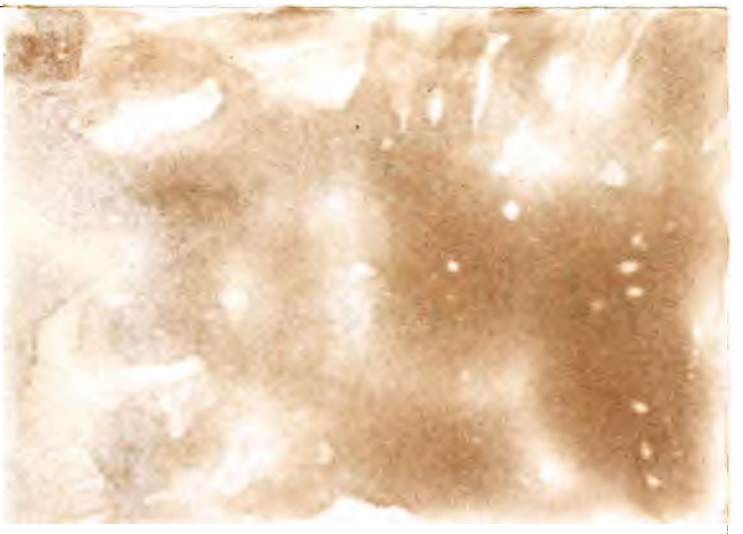

SUBMARINE TELEGRAPHY

PART I

INSTRUCTION PAPER

PREPARED BY

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SUBMARINE TELEGRAPHY

PART I

UNIV. OF

INTRODUCTION

1. Importance of Submarine Cables. The influence of submarine telegraphy on social, commercial, and political activities in all civilized nations, although perhaps but little realized by the average individual, is really very great. Submarine cables are generally established to meet political or commercial rather than social demands. In the case of the Atlantic Cable of 1868, both commercial and political needs were factors which brought financial assistance to the undertaking. The Transpacific Cable, completed in 1903, was due mainly to commercial influences, while the British Cable from Vancouver, British Columbia, to Australia was laid chiefly for political reasons. There were, in 1914, seventeen cables across the Atlantic between North America and Europe alone and many others to remote and almost unheard-of corners of the earth. The fact that there were then about 2000 cables in the world whose combined length aggregated over 300,000 miles indicates the commercial status of submarine cable telegraphy.

It is evident that, from a commercial viewpoint, the value of a submarine telegraph cable depends on the speed at which messages can be transmitted over it. And it is with this problem of transmission that we are largely concerned.

PHYSICAL FACTORS INVOLVED

2. General Properties. It is well known that a submarine cable consists of one or more copper conductors insulated from the surrounding water by gutta-percha or rubber. Long cables are made with only one conductor, which, however, is usually stranded. The actual construction of a submarine cable will be dealt with elsewhere.

A submarine cable, like any telegraph line, possesses certain physical properties which determine the characteristics of the electrical signals transmitted through it. These properties are as follows:

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1. Conductor Resistance, for which the abbreviation C.R. is used
2. Electrostatic Capacity
3. Leakage or its reciprocal, Insulation Resistance
4. Inductance
5. Absorption

Comparatively little is known as to the exact nature of the property of absorption.

3. **Resistance.** The resistance of a conductor depends on its length, sectional area, and the material of which it is made. Its value is directly proportional to the length of the conductor and inversely proportional to its cross-sectional area. This may be expressed by the formula

$$R = S\frac{l}{A} \tag{1}$$

wherein R is the resistance of the conductor; l is the length of conductor; A is its area of cross-section; and S is a constant depending on the material and on the units in which l and A are expressed—it is called specific resistivity.

When l is in centimeters and A in square centimeters, the value of S for pure annealed copper at 75° F. is 1.755×10^{-6} ohms. When l is in feet and A is in circular mils, S is 10.6 ohms at 75° F., the temperature at which the conductor resistance is usually measured. As commercial copper is not pure, its conductivity is usually expressed as a certain per cent of the conductivity of pure copper, and this percentage must be taken into consideration when calculating the resistance for commercial grades of copper. Since the working speed of a submarine cable is affected to a considerable extent by the resistance of the conductor, it is invariably made of high-conductivity copper.

The conductor of a modern cable is stranded, and its size is usually specified by its weight per mile. Its resistance is, therefore, more easily calculated from its weight than from its cross-sectional area.

A copper conductor whose conductivity is 100 per cent and whose length is l nautical miles would have, at a temperature of 75° F., the following resistance:

$$R = \frac{1183}{w}\,l \tag{2}$$

wherein w is its weight in pounds per nautical mile.*

*A nautical mile (n.m.) is 2029 yards or 1.153 statute miles.

Formula (2) can be derived from formula (1) by making a few straightforward transformations. Formula (1) assumes a cable whose length l is in feet, whose cross-sectional area A is in circular mils, and for which the value of S is 10.6. As there are 6087 feet in a nautical mile

$$l \text{ (in feet)} = 6087\ l \text{ (in nautical miles)}$$

Therefore, when l is expressed in nautical miles, formula (1) becomes

$$R = \frac{10.6 \times 6087\ l}{A} \qquad (1\ A)$$

Now the weight w in pounds per nautical mile of the cable is expressed by the formula

$$w = A\ K \qquad (1\ B)$$

wherein K is the weight in pounds of a rod of copper, 1 circular mil in cross-section and 1 nautical mile in length. The expression for K is therefore

$$K = \frac{\pi(0.001)^2}{4} \times 6087 \times 12 \times 0.318 \text{ lb.}$$

wherein the factor $\frac{\pi(0.001)^2}{4}$ is the area in inches of 1 circular mil; the factor 12 reduces the feet to inches; and the factor 0.318 is the weight in pounds of 1 cubic inch of copper. Solving equation (1 B), gives

$$w = 0.01827\ A = \frac{A}{54.74} \qquad (1\ C)$$

combining (1 A) and (1 C) results in

$$R = \frac{1180\ l}{w}$$

which agrees within a fraction of 1 per cent with (2).

As explained in "Elements of Electricity and Magnetism," Part II, p. 59, the resistance of the conductor increases with the increase of temperature, and it is given approximately by the formula

$$R_t = R_{32}\ [1 + \alpha\ (t - 32)] \qquad (3)$$

wherein α is a constant depending on the material; R_t is the resistance at a temperature of t degrees F.; R_{32} is the resistance at a temperature of 32° F.; and t is greater than 32° F. The value of α for copper may be taken as 0.0022 when the temperatures are given in degrees Fahrenheit.

Example. A certain cable is 900 nautical miles long and weighs 160 pounds per nautical mile. What is its resistance at 60° F?

From formula (2)

$$R = \frac{1183 \times 900}{160} = 6654 \text{ ohms at } 75° \text{ F.}$$

Using formula (3), first find what its resistance would be at 32° F.

$$R_{32} = \frac{Rt}{1+\alpha(t-32)} = \frac{6654}{1+(0.0022\times 43)} = 6078.9 \text{ ohms}$$

Then its resistance at 60° F. is given by

$$R_{60} = 6078.9\ (1+0.0022\times 28) = 6453.4 \text{ ohms}$$

4. Capacity. As explained in "Elements of Electricity and Magnetism," Part I, §39, when an electromotive force is applied to the two plates of a condenser—as when the positive pole of a battery is connected to one plate and the negative pole of the battery is connected to the other plate, Fig. 1—the effect is just as though a certain quantity of electricity passed through the condenser from the negative plate to the other plate. The quantity of charge a condenser has, or more exactly the quantity of charge so transferred is proportional to the difference of potential

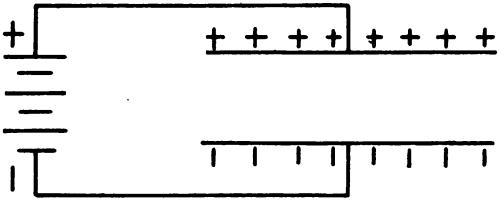


Fig. 1. Effect of Condenser on Current

between the plates. This difference of potential is equal to the applied electromotive force, when the condenser is fully charged. Therefore,

$$Q = C\ E \qquad (4)$$

wherein Q is the quantity of charge which has been transferred by the applied electromotive force of E volts; and C is a constant for a given condenser and is called its electrostatic capacity, or simply its capacity. Thus, according to equation (4), if, say, 1 volt is applied to the condenser, a certain charge Q_1 is given up to the condenser; if twice this electromotive force, or 2 volts, is applied, a charge Q_2, twice as large as Q_1, will be given to the condenser; and so on.

Hydraulic Analogy. There is a simple hydraulic analogy to the action of a condenser. Imagine a centrifugal pump P, Fig. 2A, developing a certain pressure when running with the

check valves closed. The vessel A is divided into two parts by an elastic diaphragm BB. Assume that, when the valves in both arms are opened, the pump draws water out of compartment C and forces it into D until the diaphragm is stretched to such an extent that it pushes back on the water with a force equal to that with which the water is pushed against the diaphragm by the pump. It is evident that the greater the force developed by the pump the greater the quantity of water which will be drawn out of compartment C and forced into compartment D, and the

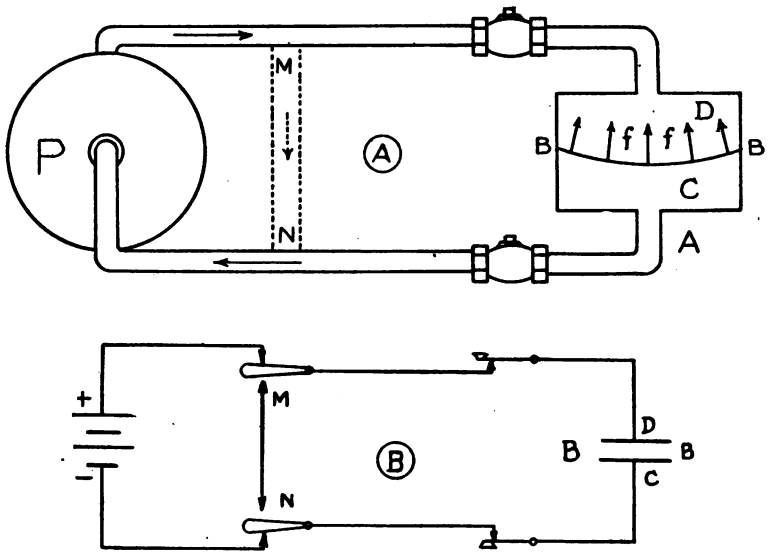


Fig. 2. Hydraulic Analogy of Condenser Action

more the diaphragm will be stretched. Equation (4) applies to this case also. The quantity of water so moved by a given force will, of course, depend on the area of the diaphragm, its thickness, and the material of which it is made. Likewise, in the electrical case, the quantity of charge moved from one plate to the other by a given electromotive force depends on the area of the plates, their distance apart, and the material of the dielectric between them. This is another way of saying that while the capacity of any given condenser as defined by equation (4) is constant, once it has been made, its actual value depends on its

size, shape, and the material of which it is composed. Fig. 2B is the electrical equivalent of this circuit, the battery at the left corresponding to the pump in Fig. 2A, and the condenser plates taking the places of the chambers C and D, and the strained dielectric between the plates corresponding to the diaphragm BB.

Calculation of Capacity of Simple Plate Condensers. If the condenser is made of flat plates which are large compared to their distance apart, its capacity is directly proportional to its area and inversely proportional to the thickness of the dielectric between the plates. That is

$$C = N\frac{A}{D} \tag{5}$$

wherein A is the area of the plates; D is their distance apart; and N is a constant depending on the material of the dielectric and the units in which A and D are given. Thus, for kerosene oil the value of N would be about twice that for air; that is, if the capacity of two flat plates separated by air were measured and the plates were then immersed in kerosene oil, the capacity would be doubled. If a piece of mica just thick enough to fill the space were put between the plates, the capacity would be increased from five to ten times its value with air as the dielectric, depending on the quality of the mica. Gutta-percha would increase the capacity of the air condenser about three times. This ratio of the capacity of the condenser with a material dielectric to the capacity of the same condenser with air as the dielectric is called the *inductivity* of the dielectric.

Examples. 1. If the capacity of two flat sheets of metal, 12 inches square and 0.01 inch apart is 0.004 microfarad, what would be the capacity of two flat metal sheets 9 inches by 8 inches and 0.02 inch apart?

Formula (5) applies and C is 0.004, A is 12×12, D is 0.01. Therefore

$$0.004 = \frac{N\times12\times12}{0.01}$$

or

$$N = \frac{0.004\times0.01}{12\times12} = 0.0000003 \text{ approx.}$$

Then for the other condenser, using primes for the purpose of distinction

$$C' = N\frac{A'}{D'}$$

or

$$C' = 0.0000003 \times \frac{9 \times 8}{0.02} = 0.001 \text{ microfarad}$$

2. On the basis of example 1, what would be the capacity of two flat metal sheets 6 inches by 8 inches, with a piece of gutta-percha 0.01 inch thick between them?

N has been found to be 0.0000003 for air; for gutta-percha it would be three times this, or 0.0000009. Therefore

$$C' = 0.0000009 \times \frac{6 \times 8}{0.01} = 0.004 \text{ microfarad}$$

In other words, with a condenser of only $\frac{1}{3}$ the area, the capacity is just as large, owing to the fact that the inductivity of the dielectric is three times as great.

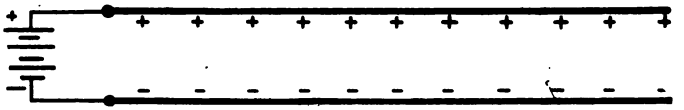


Fig. 3. Condenser Effect of Insulated Wires

If two insulated wires strung near together are left open at one end and a battery applied to the other end, as in Fig. 3, the action will be similar to that with two flat plates just described and they will form the two plates of a condenser.

Capacity of Wires Bearing Current. Consider one insulated wire and a battery connected between it and earth; the wire will then form one plate of a condenser and the earth the other, as

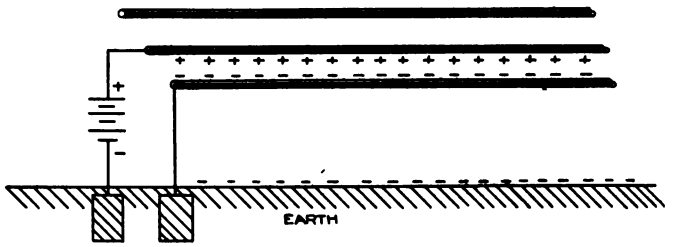


Fig. 4. Condenser Effect When Insulated Wire Is Earthed

indicated in Fig. 4. This statement assumes the earth to be a conductor of electricity, which it is, as will be explained in another section.

In general, the closer the two wires are in one case, or the closer the one wire is to earth in the other case, the greater will be the capacity of the condenser so formed. The relation between the value of the capacity and this distance is, however, not so simple as for the two flat plates. In addition, the capacity of the one wire to earth is affected by any near-by metallic objects, such as other conductors, as shown in Fig. 4. The same is true in the case of the two wires, so that in practice it is not a simple operation to calculate the capacity for such cases. A number of more or less complicated formulas for capacity are to be found in more advanced texts. The usual practice is to measure rather than calculate the capacity, and methods for doing this will be described later.

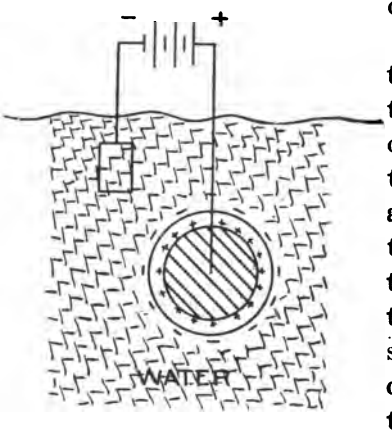


Fig. 5. Condenser Effect on Cable in Use

In case of a submarine cable the earth (water) entirely surrounds the conductor and forms one plate of a condenser when it is used as the return conductor of the circuit as shown in Fig. 5. In general, the larger the conductor and the thinner the dielectric the greater the capacity. This is to be expected, since increasing the size of the conductor is equivalent to increasing the size of the condenser plates and making the dielectric thinner is equivalent to bringing the two plates of the condenser closer together.

Of course, the area of the plates of a condenser of this kind is directly proportional to the length of the wire, and the capacity will vary in the same ratio; that is, a piece of wire 3 miles long will have 3 times the capacity of a piece of the same wire 1 mile long. The capacity of most submarine cables lies between 0.3 and 0.5 microfarad per nautical mile.

Referring to Fig. 2A it is evident that if the pump P were stopped and at the same time a by-pass pipe were connected to the two main pipes at M and N, as shown by the dotted lines, the diaphragm, which is exerting a force on the water in chamber D

owing to its elasticity, would force water out of chamber *D* around the pipes into chamber *C* until the water on both sides was at the same pressure. Similarly for Fig. 2B, if the charging battery is disconnected from a condenser and a wire connected to the two plates, the charge drawn out of one plate and forced into the other by the battery will flow back into the plate from which it came. The condenser is then said to be discharged.

5. Leakage. No material substance is a perfect insulator. Thus, if one pole of a battery is connected to earth and the other pole is connected through a galvanometer to a cable conductor insulated at the distant end, Fig. 6, a large current flows at first. This is the charging current, as explained in the previous paragraphs. After this large current has stopped flowing, owing to

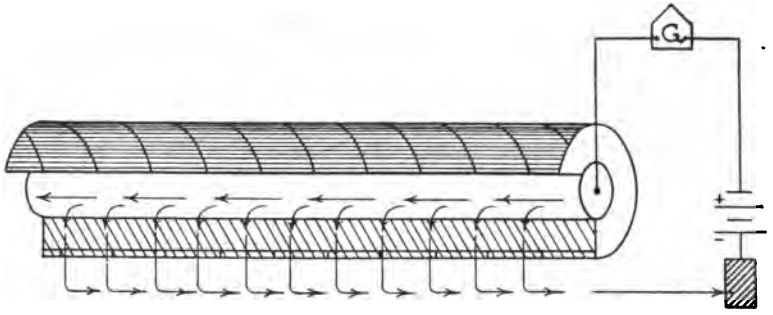


Fig. 6. Leakage from Submarine Cable

the condenser being fully charged, a small current continues to flow. This is the current which flows through the insulator or through imperfections in it.

Leakage in Submarine Cables. Great care is taken to secure good insulation for submarine cables because of the great difficulty and expense of repairing them should they become so faulty that they cannot be worked. Accordingly a high grade of gutta-percha is used. The insulation of submarine cables is usually from 250 to 2000 megohms per mile at 75° F. and atmospheric pressure, although these should not be taken as outside figures. As the insulation of a whole cable may be from 2 to 30 megohms at sea temperature and pressure, the loss in current at the receiving end from leakage is not large, and therefore the problems caused by leakage are not so important as on land lines,

TABLE I

Values of 1.08 Raised to All Powers between 1 and 40

Power(N)	1.08^N	Power(N)	1.08^N	Power(N)	1.08^N	Power(N)	1.08^N
1	1.08	11	2.34	21	5.08	31	11.02
2	1.17	12	2.53	22	5.49	32	11.91
3	1.26	13	2.74	23	5 93	33	12.87
4	1.36	14	2.96	24	6.41	34	13.91
5	1.47	15	3.19	25	6.93	35	15.03
6	1.59	16	3.45	26	7.49	36	16.24
7	1.72	17	3.73	27	8.09	37	17.54
8	1.85	18	4.03	28	8.74	38	18.95
9	2.00	19	4.35	29	9.44	39	20.48
10	2.17	20	4.70	30	10.20	40	22.13

where the leakage is often a very considerable factor. In fact, the highest obtainable insulation is not desired for reasons connected with transmission which will be pointed out later and also because it has been found to be unstable.

Effect of Temperature on Insulation Resistance. Temperature has quite a large influence on the leakage, or its reciprocal, the insulation resistance. The law of the change of resistance of gutta-percha and other insulators with change of temperature is the reverse of that for electrical conductors; that is, a decrease of temperature increases their resistance and vice versa. In addition, their change of resistance with temperature is very much larger than that of conductors and follows a different law. Formula (3) shows that in the case of conductors, the increase in resistance is directly proportional to the increase in temperature, whereas for insulators the increase in resistance for each degree fall in temperature is a certain per cent of the value of the resistance at a temperature 1 degree higher, that is, the resistance follows the compound interest law and is given by the expression

$$R_T = R_{75} K^{(75-T)} \qquad (6)$$

wherein R_T is the resistance at T degrees F.; R_{75} is the resistance at 75° F.; and K is a constant depending on the quality of the gutta-percha. A value of 1.08 for K, derived from data given by Willoughby Smith will be used here.

In order to facilitate calculations the values of the constant 1.08 raised to all powers between 1 and 40 by steps of 1 is given in Table I.

Examples. 1. The insulation resistance of a certain length of a cable is 50 megohms at 75° F. What will be its insulation resistance at 35° F., if the insulator is gutta-percha?

$$75° - 35° = 40° \text{ change of temp.}$$

Substituting in formula (6)

$$R_{35} = 50\ (1.08)^{40} = 50 \times 22.13 = 1106.5 \text{ megohms}$$

Thus it is seen that a reduction of 40° in temperature will increase the insulation resistance about twenty-two times. In the case of pure copper its resistance would have been *decreased* about 9 per cent.

2. The insulation resistance of a section of cable insulated with gutta-percha is 500 megohms at a temperature of 75° F. What would be its insulation resistance at 80° F.?

Using equation (6)

$$75° - T° = 75° - 80° = -5°$$

$$R_{80} = R_{75} \times (1.08)^{-5}$$

or

$$R_{80} = 500 \times \frac{1}{(1.08)^5} = \frac{500}{1.47} = 340.1 \text{ megohms}$$

Effect of Pressure on Insulation Resistance. Another factor which affects the resistance of gutta-percha is the pressure to which it is subjected. It has been determined that the resistance of pure gutta-percha is increased by 0.00023 of its value at ordinary atmospheric pressure for each pound per square inch increase of pressure, or

$$R_p = R_o\ (1 + 0.00023p) \qquad (7)$$

wherein R_p is the resistance at pressure p; R_o is the atmospheric pressure; and p is the pressure in pounds per square inch above atmospheric pressure.

Example. The insulation resistance of a certain piece of cable is 10 megohms at atmospheric pressure. What is its insulation resistance at a depth of 1000 fathoms of sea water?

One fathom is equal to 6 feet. The pressure of sea water increases 2.68 pounds per square inch for each fathom of depth. Hence, the pressure at 1000 fathoms due to the weight of the sea water is 1000×2.68, or 2680 pounds per square inch. Using formula (7) we have

$$R_p = 10\ [1 + (0.00023 \times 2680)] = 16.16 \text{ megohms}$$

6. Absorption. In order to simplify the foregoing discussion, a constant value was assumed for the small current which flows immediately after the charging current has ceased flowing, that is,

in case of a condenser of small area, a few thousandths of a second after applying the battery. If this were actually so, we could simply measure the value of the small current and the value of the voltage applied and by Ohm's law compute the value of the insulation resistance.

$$R=\frac{E}{I} \tag{8}$$

wherein R is the resistance in ohms; E the potential difference in volts; and I the current in amperes. However, this is not the case, for this small current decreases for some time as shown in Fig. 7.

Part of this current supplies the so-called *absorbed* charge, and the other part is that which actually flows through the insulation. This phenomenon is known as absorption. The absorption current

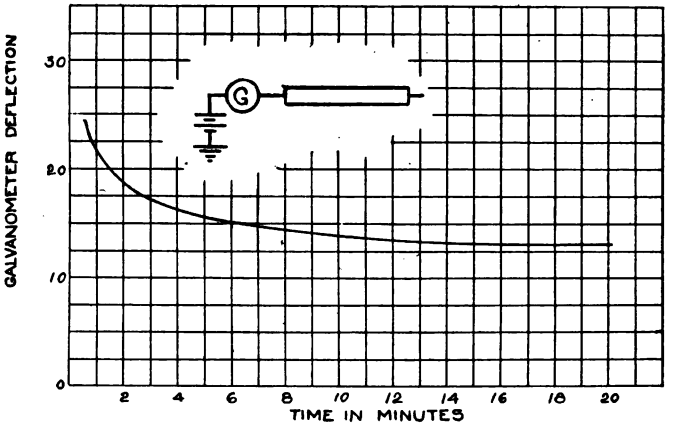


Fig. 7. Diagram Showing Variation of Current with Time of Electrification

diminishes toward zero while the true leakage current tends to become more or less constant. From the foregoing it is seen that the apparent insulation resistance depends on the time of electrification and it is necessary to specify this time when giving the value of insulation resistance. Although it requires from fifteen to twenty minutes for leakage current to become fairly steady, it is the usual practice to use the value at the end of one minute of electrification in calculating the insulation resistance, if the sample under test is not otherwise faulty. The values of insulation resist-

ance used in this text are for one minute's electrification. When definite faults exist in cables other methods are used, as will be explained under the subject of Testing.

If the testing battery is removed and the conductor connected to earth through a galvanometer, the free charge first rushes out of the condenser and then the absorbed charge leaks out as shown in Fig. 8, the current gradually dropping to zero. This is the reverse phenomenon to the absorption occurring during electrification.

7. Inductance. All circuits have inductance due to the magnetic flux set up by the current flowing in the circuit. When

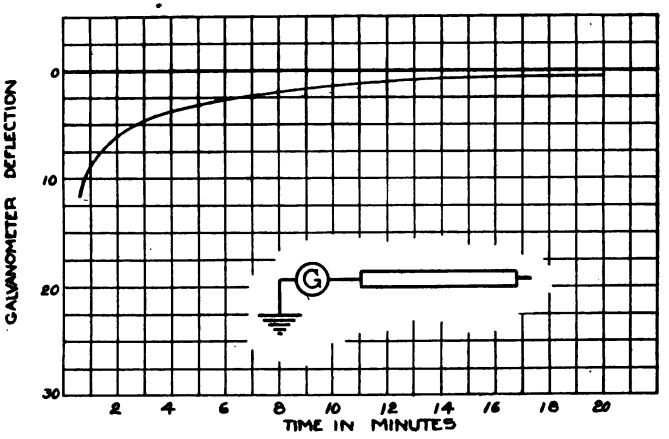


Fig. 8. Diagram Showing Flow of Current during Discharge, the Long Duration of Discharge Being Caused by the Absorbed Discharge

the current varies, it causes the magnetic flux to vary, and this sets up an electromotive force opposing the change of current. The value of this electromotive force in any given circuit is proportional to the rate at which the flux changes, and since the flux is proportional to the current (if there is no iron in the neighborhood) we have

$$e = L \times \text{rate of change of current} \qquad (9)$$

wherein e is the back-electromotive force, and L is a constant called self-inductance. The self-inductance of a submarine cable is so small that the effect it has on the value of the current received at the distant end of a cable may be ignored.

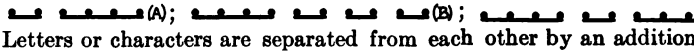
TRANSMISSION OF SIGNALS

8. Telegraph Codes. In submarine telegraphy the Continental Morse code is used. The dots and dashes, however, are distinguished differently than in land-line telegraphy.

Continental Morse for Land Lines. It will be remembered that in land-line working the distinction between dashes and dots is one of length or duration, the dashes being made three times as long as the dots when sending by automatic transmitters and approximately three times as long when sending by hand. The time length of a dot element will be considered as the unit of length by which to measure other elements.

In the Continental Morse code as used on land lines we have the following distinguishing features:

Dots are 1 unit in length; dashes are 3 units in length. Dots and dashes within a character are separated by intervals of the same length as the dot interval, as:



Letters or characters are separated from each other by an additional interval 2 units in length (total interval between letters, 3 units), as:

Words are separated by a further additional interval of 2 units (total interval between words, 5 units), as:

This is also shown by the shaded portion of the signals in column 1, Table II. When two "kinds" of current (plus and minus) are used, the spacing intervals between dots and dashes are formed by applying current of the opposite polarity to that applied in forming the dot and dash elements, as indicated by that part of the graph below the dotted zero line in column 1, Table II.

Continental Morse on Submarine Cables. In submarine telegraphy three "kinds" of current are used (plus, minus, and zero), the dot and dash elements each being of the same duration, one unit, but being formed by currents of opposite polarities. It is usual to assume dots to be formed by positive current and represent them in drawings by curves above the zero line. Similarly dashes, formed by negative current, are represented by curves below the zero line, as shown in columns 2 and 3, Table II. The spacing intervals of zero current are obtained in the ordinary system by earthing the cable. The zero interval between letters is 1 unit

in length and that between words is 3 units in length (2 units in addition to the 1 belonging to the last letter). As sent by some automatic transmitters, and as automatically repeatered between cables, there is no interval between dots and dashes in a character and there need be none for purposes of reading or deciphering as can be seen from the signals in column 2, Table II and as is explained elsewhere. However, with hand sending there is necessarily some interval between dots and dashes in a character and with automatic transmission it is the usual thing in order to improve the transmission, to put a zero interval of some length between all dots and dashes. This zero interval between dots and dashes is sometimes $\frac{1}{2}$ of the total dot interval, but more frequently it is about $\frac{1}{3}$ of the total dot or dash interval, as shown in column 3, Table II.

9. Comparison of Codes. When comparing codes, this short zero interval should be considered merely as changing the wave shape of the applied voltage within the dot interval, and not as increasing the number of units in a given character; that is, the corresponding signals in columns 2 and 3 are considered as being the same number of units in length. As the signals are received no current of frequency higher than the fundamental dot–dash reversal frequency will be noticeable with either type of transmitted signal. It will be noticed that any signal transmitted as shown in column 3 would, on passing through a cable relay, be re-transmitted as shown in column 2 without, of course, changing its length as measured in units.

The numbers shown on a line with each character represent its length for land and submarine working as measured in unit intervals, including the regular unit spacing interval necessary to separate one character from another.

Adding the lengths of all the letters of the alphabet and dividing by 26 it is found that for submarine working the average length of a letter, including its letter space, is 4.15 units. This average would only apply to secret cipher code messages in which all letters of the alphabet occur the same number of times on the average; the words are unpronounceable. The length of each numeral is 6 units when using the full dot and dash combination, called the *long figures*. The abbreviated combinations, known as *short figures*, are sometimes used for certain numerals.

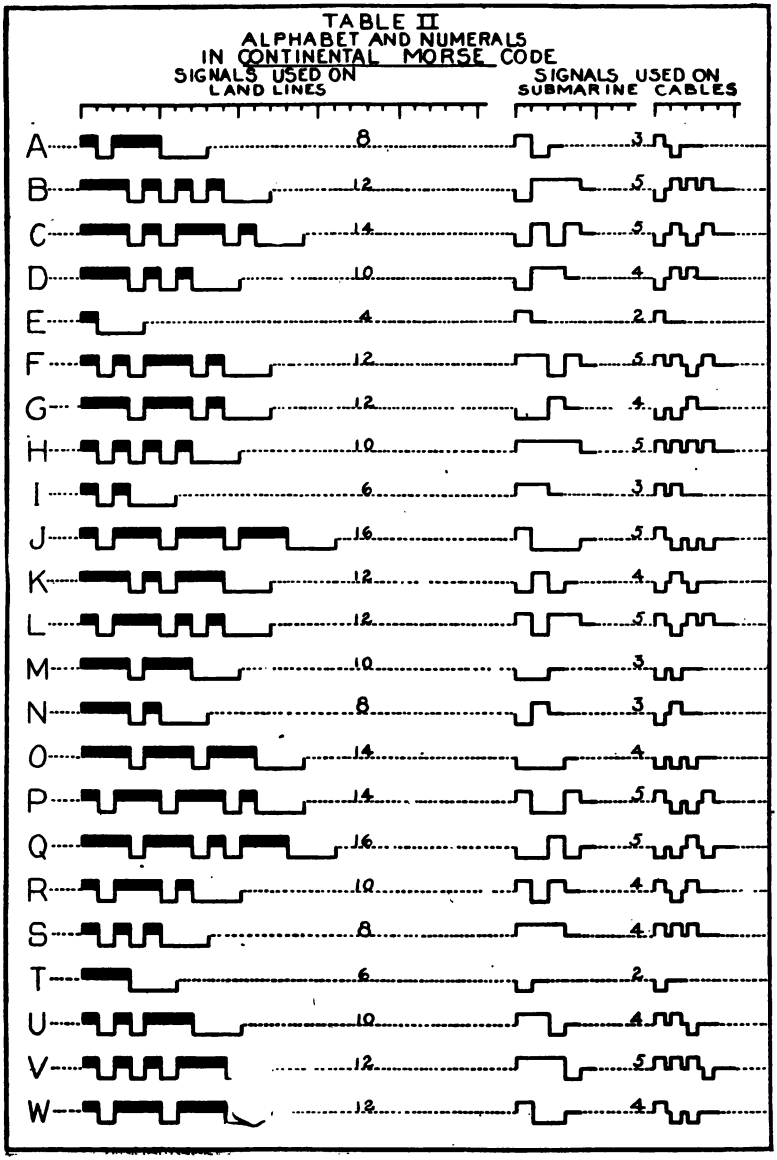
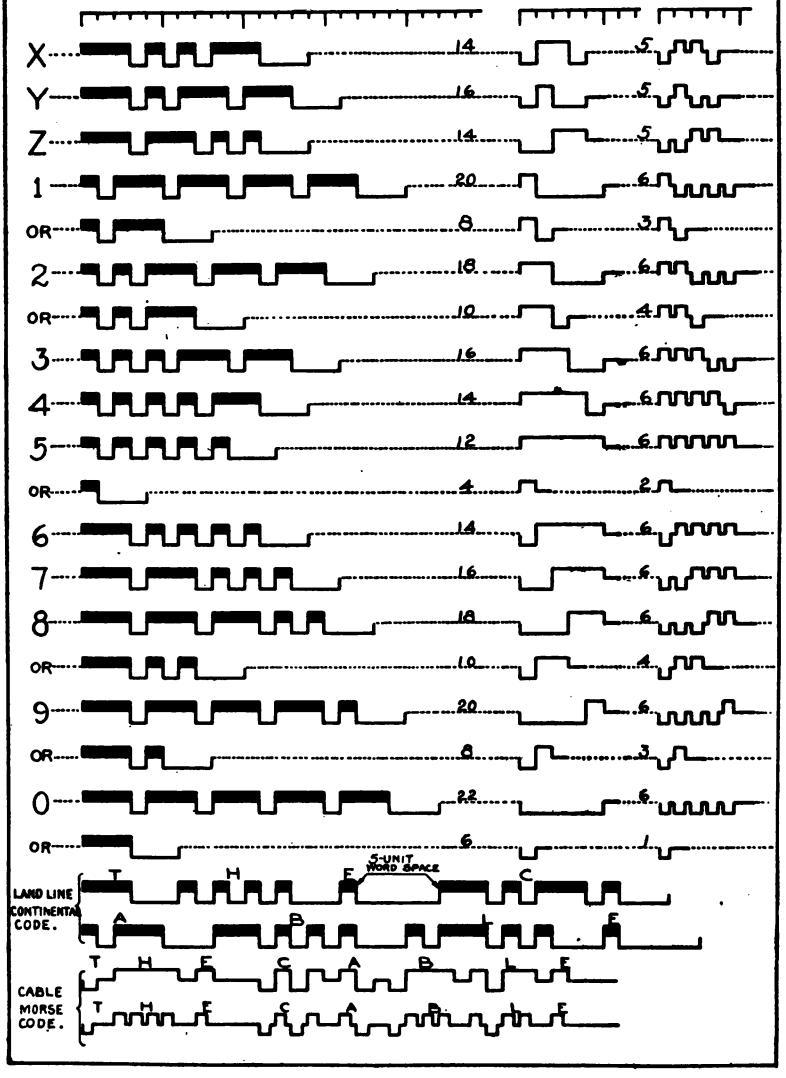


TABLE II
ALPHABET AND NUMERALS
IN CONTINENTAL MORSE CODE
SIGNALS USED ON LAND LINES
SIGNALS USED ON SUBMARINE CABLES
A 8 3
B 12 5
C 14 5
D 10 4
E 4 2
F 12 5
G 12 4
H 10 5
I 6 3
J 16 5
K 12 4
L 12 5
M 10 3
N 8 3
O 14 4
P 14 5
Q 16 5
R 10 4
S 8 4
T 6 2
U 10 4
V 12 5
W 12 4

TABLE II (CONTINUED)



In comparing codes the word space may be considered as an extra character to be transmitted and used as such in determining the average length of a character. Thus on the above basis a 10-letter code word would have 11 characters and a total length of $(10\times4.15)+2$, or 43.5 units. Then the average length of a character would be $\frac{43.5}{11}$, or 3.95 units. Any numerals in the message would bring the average above this, if the long combinations were used.

However, when the plain English language is used, as in press dispatches and many personal cablegrams, some letters occur more frequently than others. The Morse code is arranged so that those letters occurring the most frequently in plain English have the short combinations of dots and dashes. Thus the average length of a letter, including the one letter space in this class of traffic is found to be about 3.6 units, as can be demonstrated by adding all the units necessary to transmit the *letters* in, say, a fairly long representative press article and dividing by the total *number of letters*. Now, if it is assumed that the average length of a word is 6 characters, 5 letters and 1 word space, the average length of a *character* is found to be $\frac{(5\times3.6)+2}{6}$, or 3.33 units. Any numbers in the message such as dates, etc., make the average slightly higher than this. The average length of a character would also be different if the average word were assumed to have a greater or less number of characters in it. The average length of a character, including numerals, is thus seen to depend, in general, on the relative amounts of code and plain English traffic, and the value 3.7 units will be taken for this average. Then the speed of a cable in characters per minute, usually called *letters per minute* (L.P.M.), can be derived by dividing the total number of units transmitted per minute by 3.7. Since each center hole of the transmitting tape corresponds to 1 unit, either a dot, dash, or space, it is only necessary to determine the number of center holes passing through the transmitter per minute in order to calculate the speed in letters per minute, according to the preceding arbitrary relation. The speed of received signals can similarly be determined by punching up the words received in a minute and

counting the center holes. However, in comparing the speeds of cables, when the same code is used, there is no need to transform units per minute to letters per minute, for the comparison might better be made in units per minute, units per second, or cycles per second; the last named is the form generally used. Two unit periods are considered the length of 1 cycle, as indicated in Fig. 9, so that the speed in cycles per second is one-half of the speed as given in units per second.

It is evident that the above method of determining the length of the average letter (character) is most useful in comparing various codes, the average length of characters in each code being determined in the same way. Thus the average length of a character (letters and word spaces) for plain English language in the Continental Morse code as used on land lines is about 8.5 units.

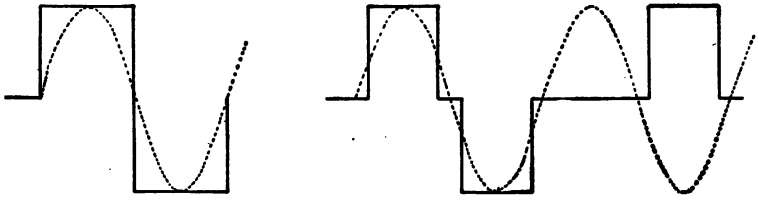


Fig. 9. Diagram Showing Relation between Length of Signals in Dots and Dashes and Their Equivalent Length in Cycles

This indicates the advantage secured in using the cable Morse code with its three "kinds" of current. The comparison of cable speeds is best made in terms of units or cycles per second, although it may be made in letters per minute determined from the speed in cycles per second by some arbitrary transformation. The probable actual number of letters and numerals per minute transmitted, not counting word spaces, may be derived from this nominal number of letters (characters) per minute by assuming a certain number of letters per word and subtracting the spaces from the nominal number of letters. Thus, if every sixth character were a word space, the actual letters per minute would be $\frac{5}{6}$ of the nominal letters per minute, and the length of a letter as so defined would be 4.44 units on the basis of 3.7 units for the length of the character. However, the so-called *actual letters per minute* would be of no more value than the *nominal letters per*

minute in comparing speeds and of doubtful value in determining the revenue corresponding to a given frequency.

ARRIVAL CURVES

10. General Problems. One of the first things that strikes the attention in a study of cable telegraphy is the comparatively low frequency at which dots and dashes are sent and received over a long cable circuit. An explanation of this will be given here in a descriptive way, only, as the necessary mathematical treatment would be too advanced for a text of this kind. Anyone wishing to go more deeply into the solution of this problem is referred to Heaviside's "Electromagnetic Theory," Vol. II, or "The Theory of the Submarine Telegraph and Telephone Cable" by Malcolm.

Effect of Capacity of Cable. A submarine cable has, by virtue of its structure and dimensions, a large electrostatic capacity between its conductor and the sheath or ground. When a difference of potential is applied between the conductor and the sheath or ground, the cable acts like a large condenser and therefore requires a considerable quantity of electricity to raise its potential appreciably. Furthermore, it takes a considerable length of time for the charge to flow to and from the distant end of the cable because of the resistance of the conductor. The manner in which this affects the transmission of signals is explained in §11.

Effect of Leak. In a simple circuit, having resistance only, the current is always directly proportional to the applied voltage and at each instant has the same value everywhere in the circuit. This value as given by Ohm's law is

$$I = \frac{E}{R} \qquad (10)$$

Thus, the instant the key is closed at A, Fig. 10, a current of I amperes flows through the circuit and continues at this value as long as the voltage E remains constant.

Now consider the case in which there is a leak on the circuit, say in the middle as shown in Fig. 11. The current starting at A will be divided at B, one part going through the leak resistance to earth and back to the battery at M, and the other part going

on to the end of the line at C and returning to M through the earth. The formulas for the calculation of the current in such a divided circuit are given in "Elements of Electricity and Magnet-

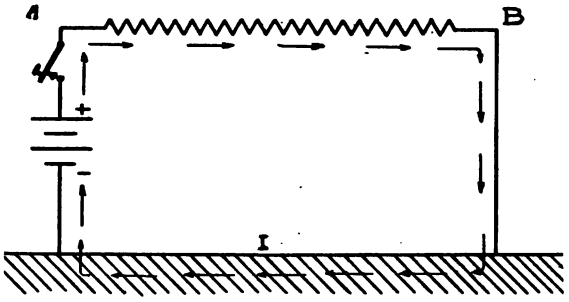


Fig. 10. Flow of Current When Circuit Is Closed

ism," Part II, p. 66. It is evident that if there is a low resistance leak at B, not very much current will reach C, and that if the resistance of this leak is increased, more current will reach C. If the resistance of the leak is increased until it is infinitely great (which is equivalent to no leak), all the current leaving A will reach C as in the case illustrated in Fig. 10.

In Fig. 12 the curve I_r shows how the current flowing beyond the point B, Fig. 11, is increased by increasing the leak resistance.

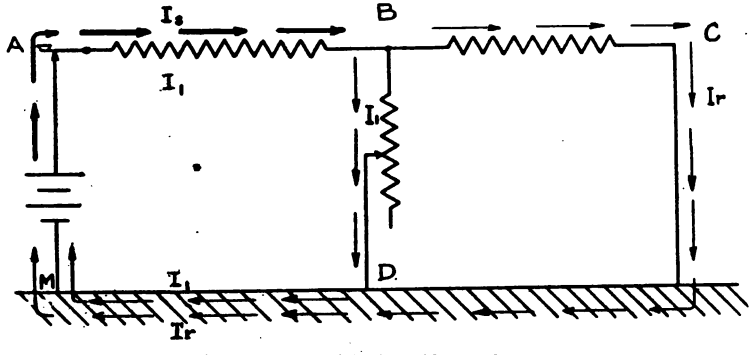


Fig. 11. Effect of Leak on Flow of Current

It will be noticed that the total current I_s flowing into the line at A is actually decreased at the same time that the current I_r is increased until they are equal when the leak is entirely removed.

11. Artificial Line of Two Sections. In order to get a clear idea of the effect of capacity on the transmission of signals over a

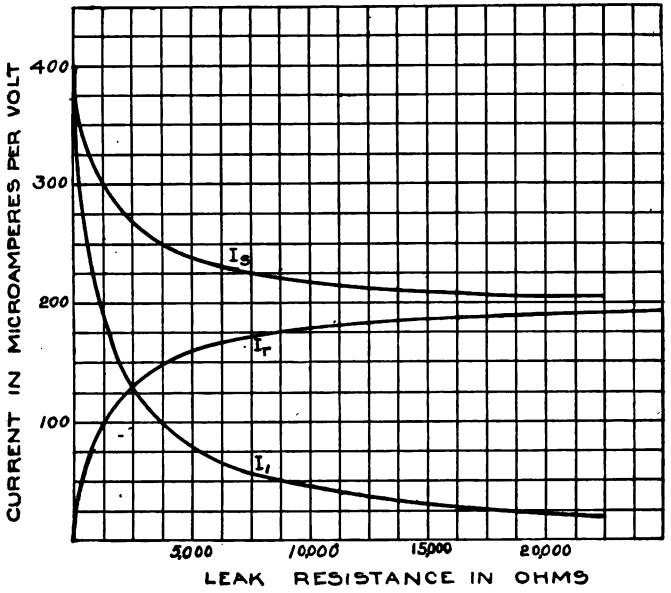


Fig. 12. Current in Various Parts of Circuit Shown in Fig. 11; Total Line Resistance 5000 Ohms

cable, consider the simple case of a cable circuit having all its capacity located at the middle, Fig. 13. This, of course, would

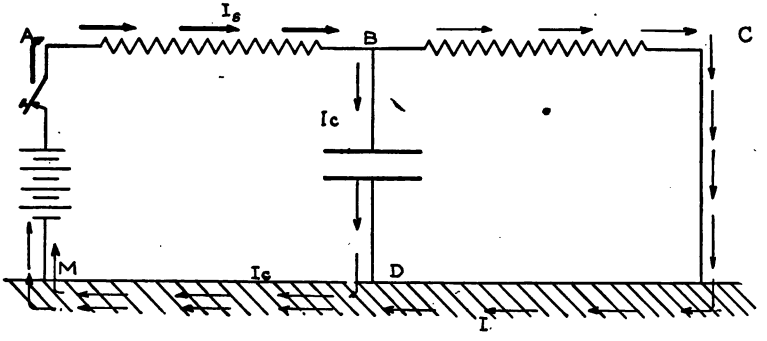


Fig. 13. Course of Current through Two-Section Artificial Cable

not be possible in the case of a real cable, but such an artificial cable can be easily constructed.

When the battery switch at A is closed, current starts flowing over the line, but at first the larger part of it flows into and charges the upper plate of the condenser; this charges by induction the lower plate of the condenser and then an equal amount flows out of the lower plate and back to the battery at M. As the condenser gets a larger and larger charge, the potential difference between its plates increases, less and less current flows into it, and more current flows into the section BC. When the condenser becomes fully charged, no current flows into it and the entire line acts

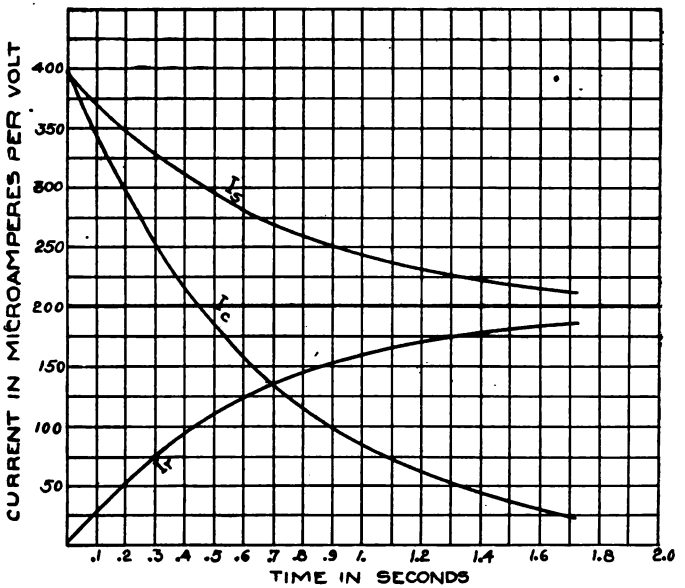


Fig. 14. Current in Various Parts of Two-Section Artificial Cable Shown in Fig. 13

like a line having resistance only, the current obeying Ohm's law. Thus the condenser acts somewhat like a leak whose resistance is continually increasing.

Fig. 14 shows how the current I_r flowing from C, Fig. 13, to ground increases with the length of time elapsing after the key is closed. It is to be noted that the current into and out of the condenser gradually decreases to zero and that the current at the sending end A, which is represented by the curve I_s and is, of course, at all times equal to the sum of the two currents I_c and I_r, decreases

gradually to the steady direct-current value as determined by Ohm's law, that is, after a certain length of time the same value of current flows in all parts of the main resistance circuit. The curves are for an artificial cable having a total resistance of 5000 ohms and a total capacity of 500 microfarads.

12. **Artificial Line of Three Sections.** If the same total resistance is divided into three sections and the same total capacity is divided into two parts, located as shown in Fig. 15, a somewhat different state of affairs obtains during the interval between the closing of the key and the time when the current has practically reached its steady value. It is rather difficult to describe just

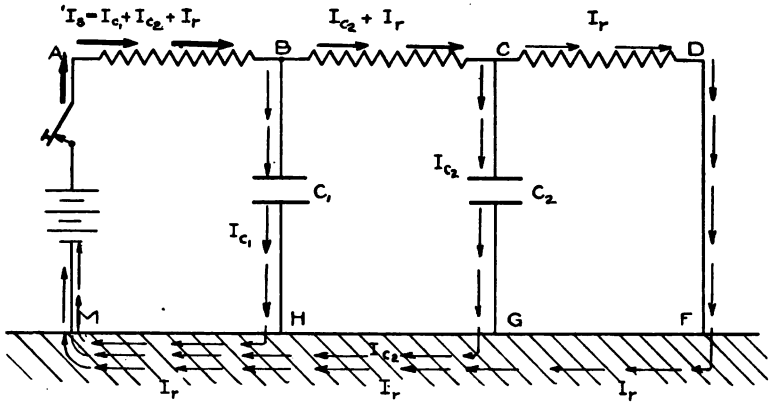


Fig. 15. Course of Current through Three-Section Artificial Cable

what happens without the use of mathematics, but it may be considered somewhat as follows:

At first the greater part of the current rushes into the condenser C_1, and as this condenser receives a greater and greater charge and the difference of potential between its plates becomes larger and larger, more of the current passes on to condenser C_2. As condenser C_2 becomes more fully charged, a larger and larger current I_r flows to earth at D. Of course, it can only be described as if these changes were in steps, when as a matter of fact these more or less complicated phenomena are taking place continuously and the current I_r is increasing gradually. These conditions are illustrated by the set of curves in Fig. 16.

It will be noted that at the first instant all the current flows through the condenser C_1, then some current starts flowing through condenser C_2, and finally the current I_r starts to flow through resistance section CD and gradually increases to the steady value as determined by Ohm's law, just as in the case with an artificial line of two sections. It will also be noted that the sending cur-

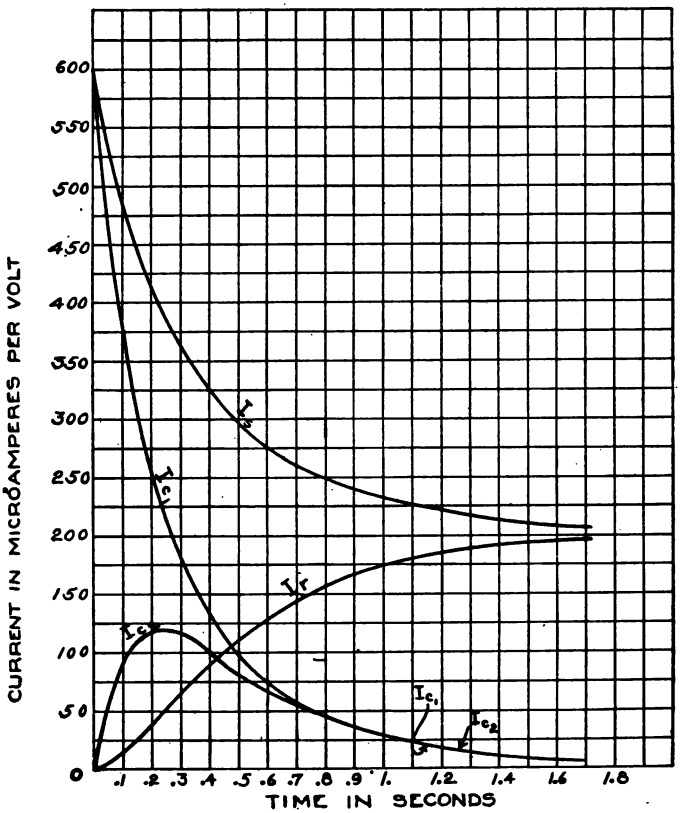


Fig. 16. Current in Different Parts of Three-Section Cable Shown in Fig. 15

rent I_s*, which flows into the circuit at A at the instant the key is closed, is larger than when the line was made up of two sections only but that its value drops off more rapidly.

In Fig. 17 a comparison is given between the curves for the received current and the sent current over artificial lines made up

*$I_s = I_{c_1} + I_{c_2} + I_r$.

of two and three sections, each artificial line having the same total resistance and the same total capacity.

13. Four-Section Artificial Line. If the artificial line is now divided into four sections, the current sent into the line will be still larger at the instant the key is closed than with a three-section line, as will be seen by comparing the curves of Fig. 18

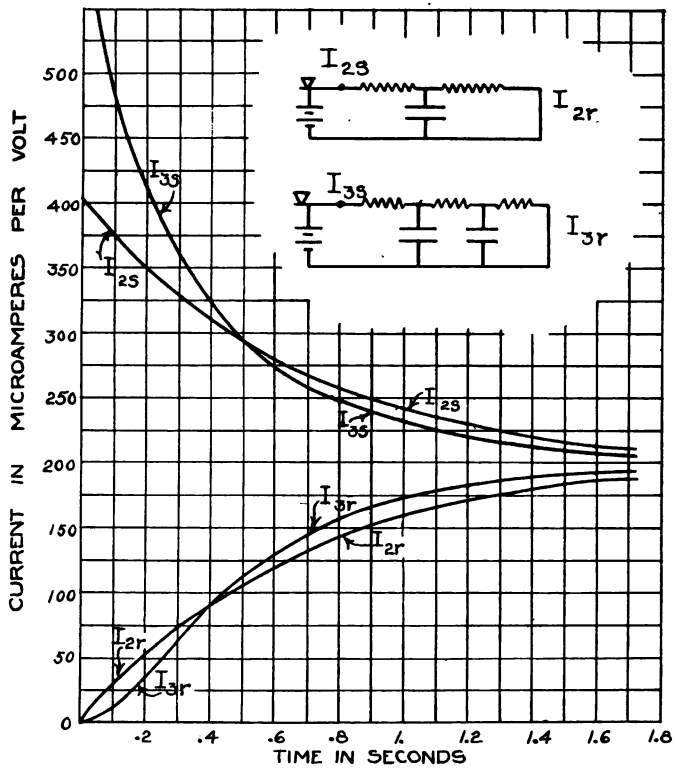


Fig. 17. Comparison of Sending and Receiving Currents for Artificial Lines of Two and Three Sections; Prolonged Application of Battery

with those of Fig. 17. The current I_r received at the distant end rises at first more slowly and then more rapidly than in the three-section line and, of course, grows to the same final value as before.

The total capacity of the line might be subdivided into a larger and larger number of parts located at equal intervals along the line until the subdivision had been carried so far that the capacity might be considered as evenly distributed.

14. Real Cable with Capacity Uniformly Distributed. In the case of a real cable the capacity is uniformly distributed along its length so that it is equivalent to the artificial line that would result if the subdividing process were carried to its limit.

The way in which the current I_r at the receiving end builds up to its full value in such a cable is shown in Fig. 19. This is

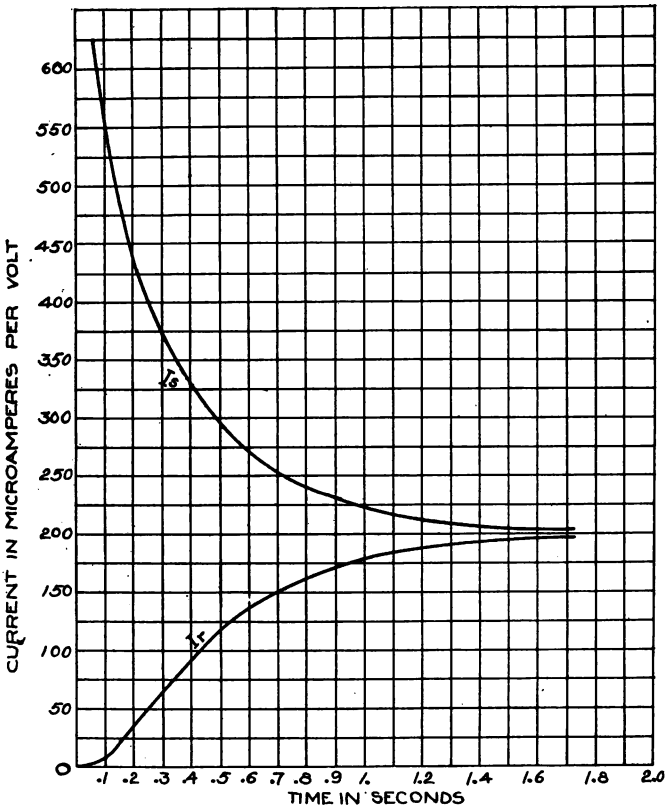


Fig. 18. Current at Sending and Receiving Ends of Four-Section Artificial Cable

known as the Kelvin arrival curve because it was first calculated by Lord Kelvin. It is here given for a cable whose total resistance and capacity are the same as those of the artificial cables just considered.

The total current I_s which goes into the cable at the sending end is also shown in Fig. 19. It should be noted that this cur-

rent is not shown at the instant the key is closed as it is extremely large at that instant, being limited only by the resistance of the battery and the connecting wires. In practice the values differ considerably from those shown owing to the apparatus connected to the cable, as will be explained later. In Fig. 20 the arrival

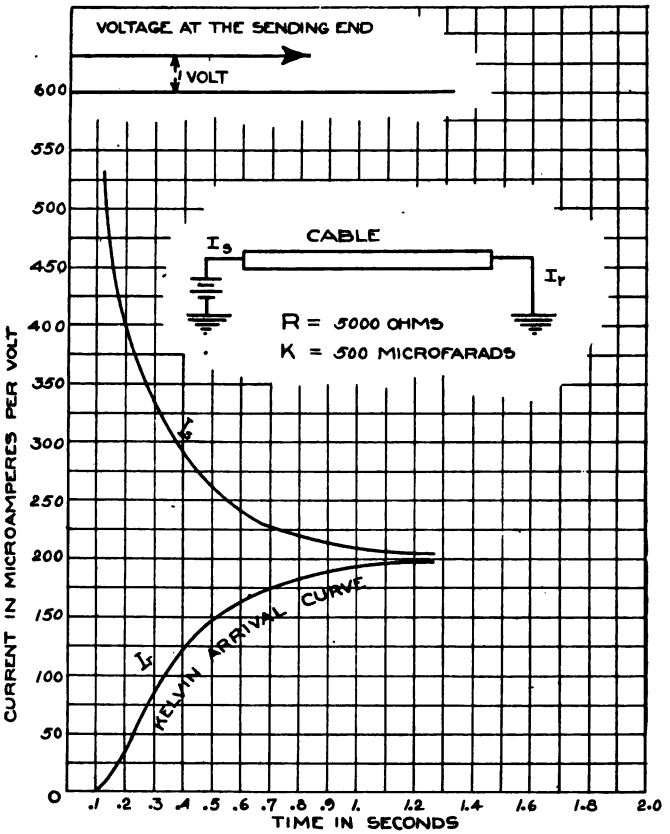


Fig. 19. Sending and Receiving Currents on a Real Cable

curves I_{2r} and I_{4r} for the various artificial lines and the curve I_r for a real cable having the same total resistance and capacity are compared.

15. Earthing Cable after Applying Battery. Next consider what would happen if, after allowing the current to become steady, the battery were removed and the sending end were earthed in

the case of an artificial line of two sections as shown in Fig. 21. The condenser, being charged, would then discharge equally

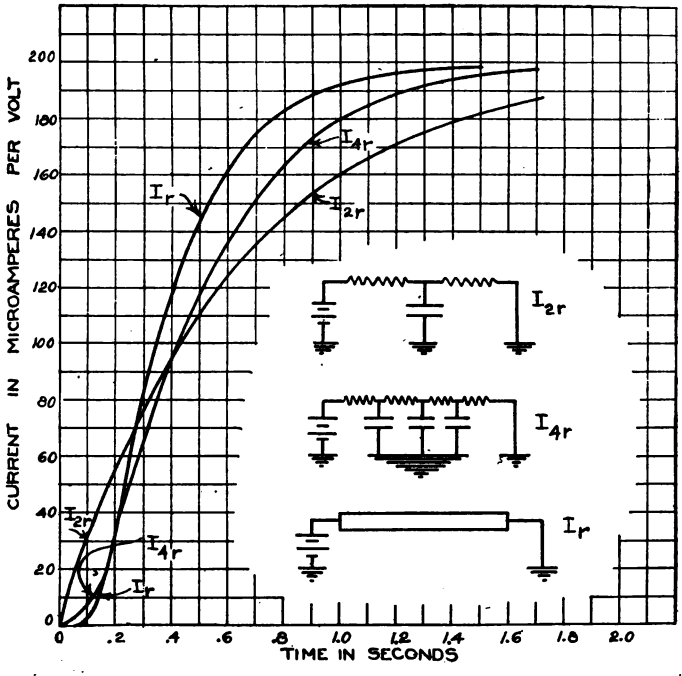


Fig. 20. Comparison of Arrival Current on Real and Artificial Cables, with Prolonged Application of Battery

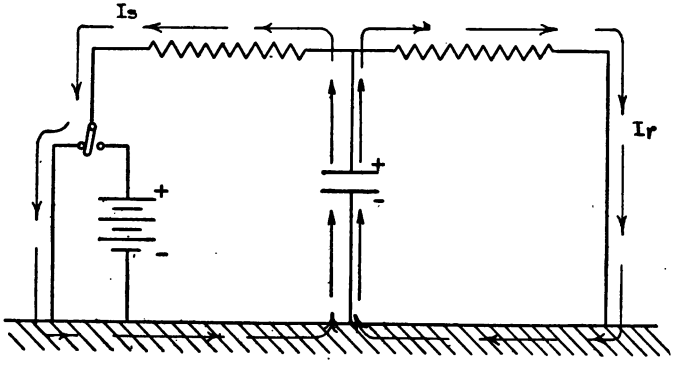


Fig. 21. Effect on Circuit of Earthing Cable after Applying Battery

through the two ends of the line, as shown by the curves in Fig. 22. The curve I_s (current at sending end) is drawn below

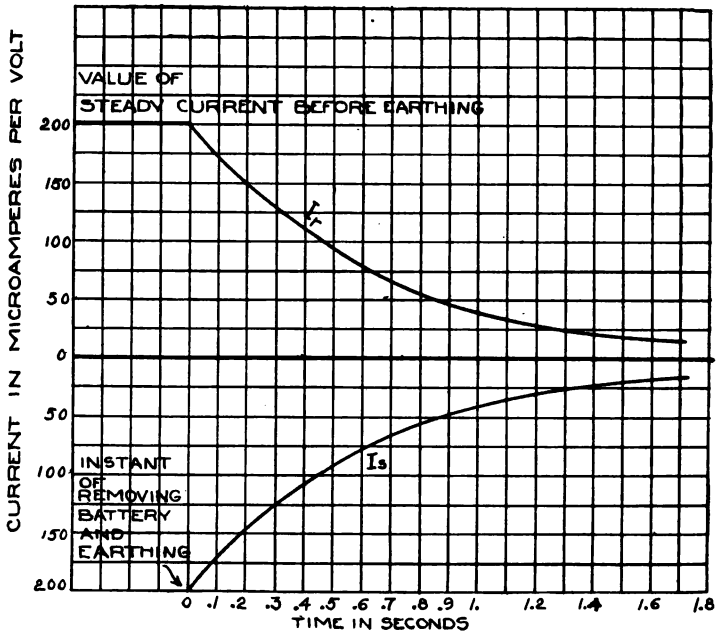


Fig. 22. Current in Various Parts of Two-Section Artificial Cable after Removing Battery and Earthing

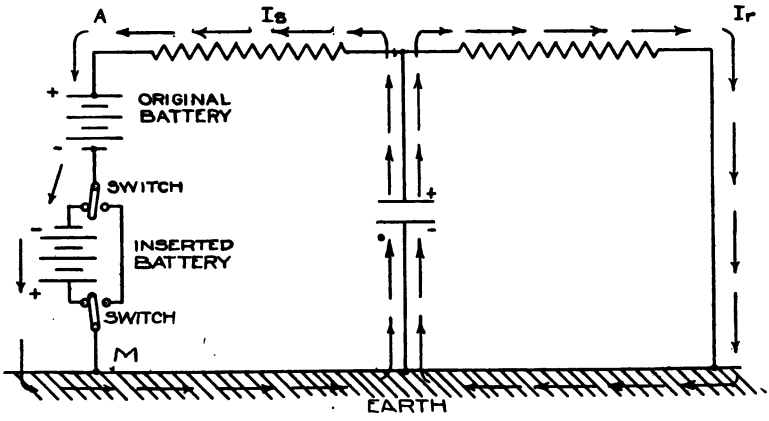


Fig. 23. Effect on Circuit of Connecting Battery of Equal Potential and Opposite Direction

the base line because the current is now flowing in the opposite direction to that when charging. It will be seen from Figs. 13 and 15 that the current I_r at the receiving end will continue to flow in those cases in the same direction during discharge as during charge.

Opposing Battery with Another Battery. It is evident that if instead of earthing the sending end of the line we had connected in series with the original battery, another battery of the same potential but opposite in direction, the same result would have been secured, Fig. 23.

After inserting this battery there would be no difference of potential between A and M because the two batteries would

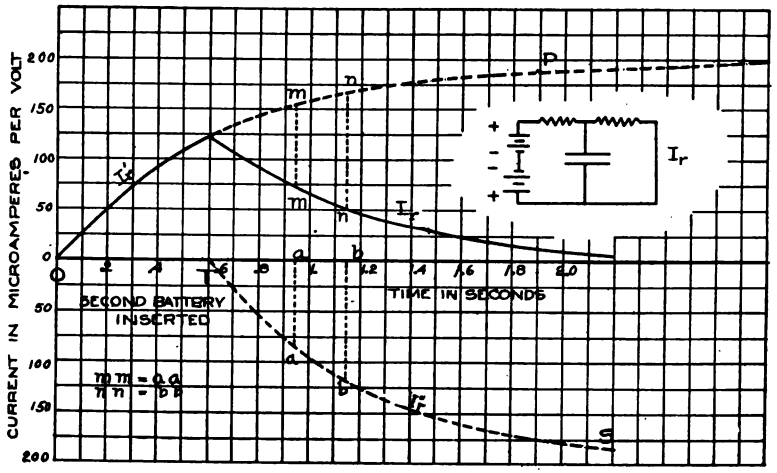


Fig. 24. Diagram Showing Formation of Signals by Insertion of Additional Batteries

oppose each other and the condenser would discharge as before. However, in this case we might consider the current as being due to the inserted battery, as, of course, it is; that is, we might consider the current due to the original battery as continuing to flow and the current from the inserted battery as building up in the opposite direction at the same time. Thus the actual current in the circuit would at all times be the algebraic sum of the two currents—their difference when they are in opposite directions. The inserted battery would produce a current I_r'' which varies the same with time as the current I_r' produced by the original

battery; that is, the arrival curves for the current from each of these batteries are the same, since they act on the same circuit. However, the current I_r'' would be in the opposite direction to I_r' and would start at a later time. It would finally reach the same steady value as I_r' and then there would be no current flowing because I_r'' and I_r' would exactly cancel.

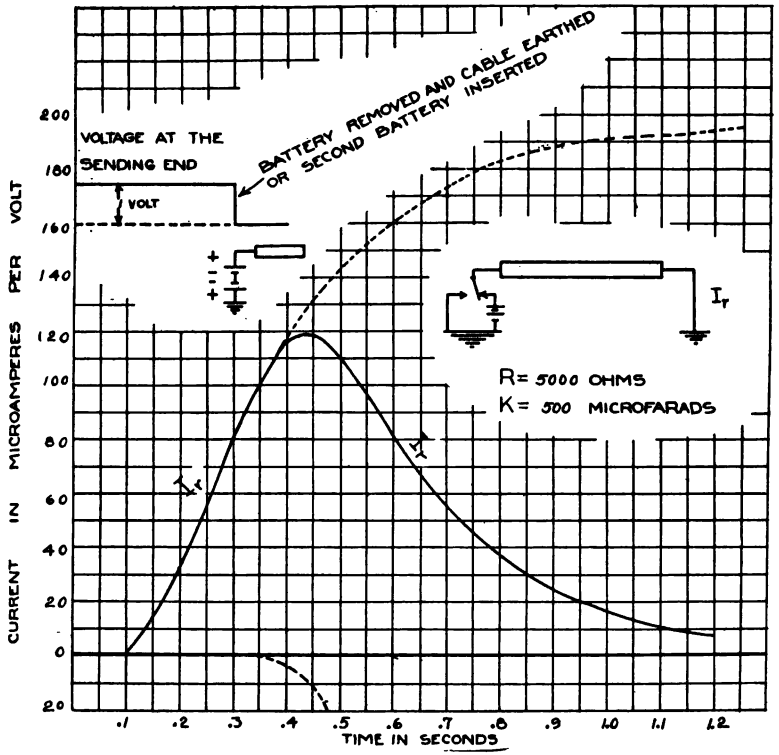


Fig. 25. Arrival Curve for Dot of .3 Second Duration

Graphical Analysis. This method of visualizing the phenomena which take place when a cable is earthed after applying a battery by considering the action as equivalent to applying an additional opposing battery is indicated in Fig. 24. Here I_r', the current due to the original battery, is represented as continuing indefinitely, or for the length of time that this battery is connected to the line.

As it is the only battery connected to the line for .6 second, that is, from O to T, I_r' is the actual arrival current at the distant end.

At the point T the second battery is inserted, and if it were to act alone, it would produce a current I_r'' in the opposite direction to I_r'. As explained before, the actual current I_r at the distant end due to the two batteries is the sum or difference of these two currents, depending on whether they are in the same or opposite directions. The currents I_r' and I_r'' can be subtracted graphically as shown. Lay off a curve TS just like the curve OP but opposite in direction. Then take any ordinate as aa and lay off an equal length downward from the curve OP, as mm. In the same manner lay off the ordinates corresponding to a number of other abscissas and connect the new points m, n, etc., by a curve. This curve I_r will be the arrival curve due to the two batteries acting at the same time, which in this case is equivalent to earthing the line.

This process can be carried out whether the original current I_r' has or has not reached its steady value when the second battery is inserted.

16. Formation of Dots or Dashes on Real Cable. *Use of Arrival Curve.* This method of plotting an arrival curve can also be used when the capacity is uniformly distributed, as in a real cable, by using the Kelvin arrival curve. For example, Fig. 25 shows the arrival curve of the current at the distant end of a cable for a dot lasting 0.3 second on a cable whose total resistance is 5000 ohms and whose total capacity is 500 microfarads. By referring to the curve, we find that the actual arrival current reaches a maximum value of 120 milliamperes. This is the same cable as shown in Fig. 19 for which the Kelvin arrival curve is drawn.

Influence of Time Element on Speed of Signal. From the dotted portion of the curve we see that if the original battery were left connected long enough, the current would finally reach a value of 200 microamperes per volt, but it would take quite a long time. If we applied 50 volts and used on such a circuit an ordinary relay operating on 5 milliamperes, it would take about $\frac{1}{3}$ of a second from the time the key at the sending end was depressed until the relay at the distant end responded. Furthermore, the current would take an appreciable length of time to decrease to such a value that the relay would release, which would mean very slow signaling.

To overcome this difficulty an instrument had to be devised which would operate on very much smaller values of current. The first instrument to accomplish this was the galvanometer invented by Lord Kelvin (then Professor William Thomson), which will be described later.

The shorter the duration of the dot the smaller the received current, as will be noted by comparing Fig. 25 with Fig. 26. Thus, when the duration of the dot is reduced to 0.1 second, the maximum value of the received current I_r is 46 microamperes

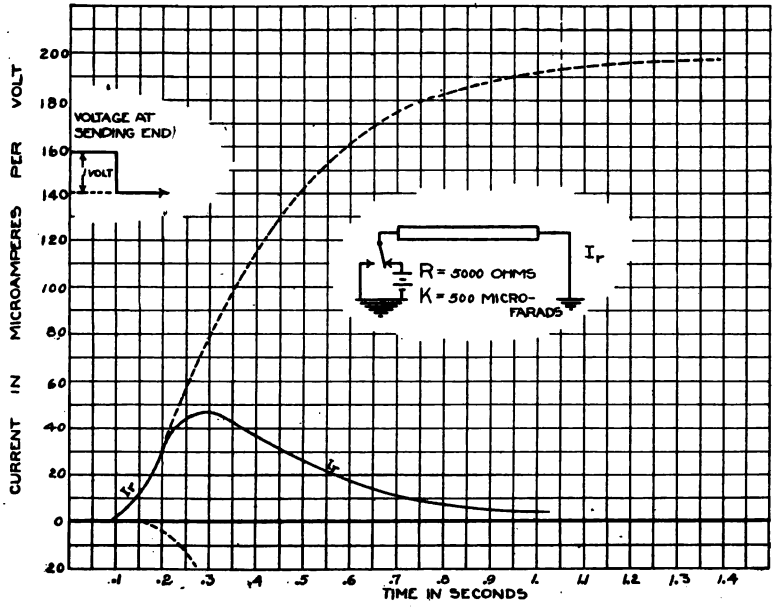


Fig. 26. Arrival Curve for Dot of .1 Second Duration

per volt. As this shorter duration of the dot corresponds to a higher speed of signaling, it is essential for rapid operation that the receiving device be as sensitive as possible, compatible with the ability to move rapidly.

Comparison of Land and Submarine Signals. In land-line telegraphy the dots and dashes are distinguished by their length, with automatic transmission a dash being three times as long as a dot. In the case of hand sending, this is also the approximate ratio. On the other hand, in submarine telegraphy a dash is of

just as long duration as a dot, but the current is in the opposite direction. An interval of *no-current* equal to the duration of a dot is used to separate the combination of dots and dashes forming one character from those forming the next following character. This will of course permit of more letters being sent in a given

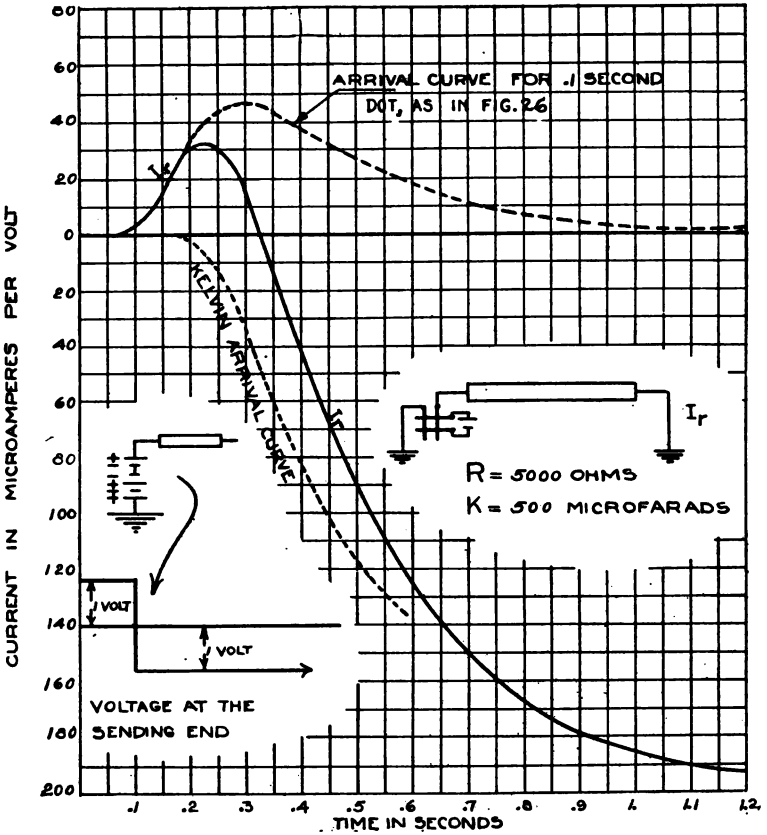


Fig. 27. Arrival Curve for Sending Potential Indicated in Insert

length of time than if dashes three times as long as dots were used. This matter is more fully discussed under the subject of Codes.

17. Building Up Arrival Curves. The method of determining the shape of the arrival curves for dots of different lengths of duration is shown in Figs. 25 and 26. The same method may be followed in building up the arrival curve for any combination of

dots and dashes. Thus, instead of considering the potential at the sending end of the cable as being alternately raised and lowered from earth potential (that is, made alternately positive and negative) by reversing the connections of a single battery and as being brought back to zero potential by earthing the cable, we may for this purpose consider the potential at the sending end of the cable as being brought to the proper values for forming the

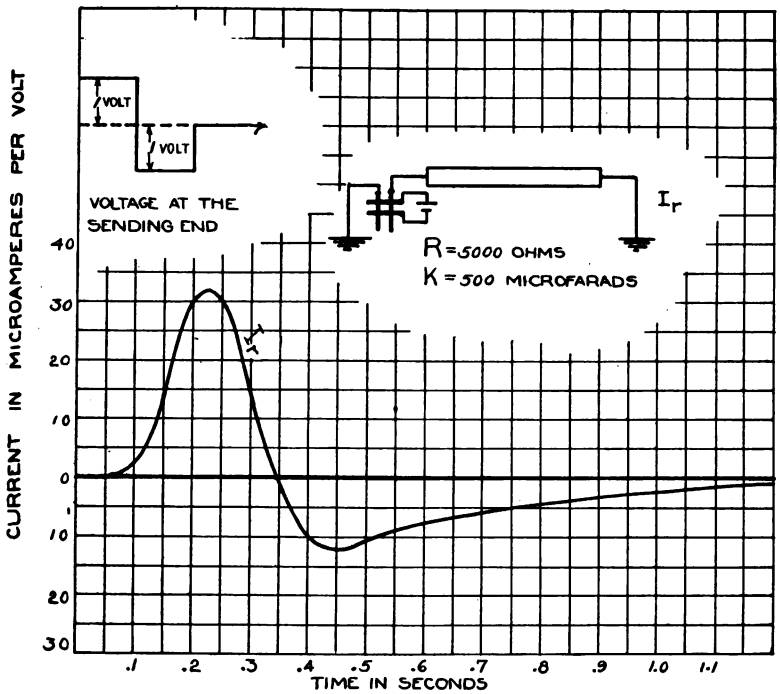


Fig. 28. Arrival Curve for Letter "A"

signals by leaving on whatever batteries have already been applied and always adding *another* battery whose potential is of the proper magnitude and polarity to produce the desired resultant potential at the sending end of the cable. It will be remembered that the arrival current for the dot was built up by adding to one Kelvin arrival curve at the proper place, another arrival curve *below the base line* to represent the result of bringing the cable back to zero potential at the sending end. Therefore, to obtain the arrival

curve for a reversed potential at the sending end, it would be necessary to consider that another battery had been added; therefore, another Kelvin arrival curve must be added to the above dot arrival curve, as shown in Fig. 27.

Arrival Curve for Letter **A.** If now, after 0.1 second, we wished again to bring the sending end of the cable back to earth potential, thus ending the negative pulse, we might add another battery with its positive pole to the cable. In practice we would

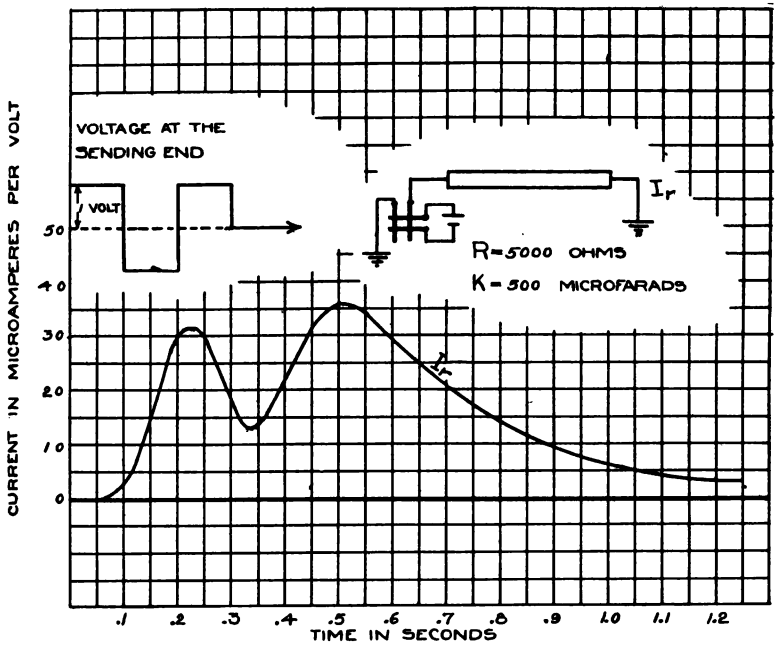


Fig. 29. Arrival Curve for Letter "R"

simply earth the sending end of the cable. Thus to get the new arrival curve, we would add to the arrival curve of Fig. 27 at the proper place another Kelvin arrival curve *above the line,* resulting in the curve shown in Fig. 28.

We can thus build up the arrival curve corresponding to any combination of applied potentials by adding and subtracting a certain number of Kelvin arrival curves spaced at the proper time intervals. The arrival curve corresponding to a positive potential applied to the cable is always drawn above the base, or zero, line

and vice versa. . The dot signal is produced by applying a positive potential to the cable for a short interval and its curve is therefore drawn above the zero line. The dash, which is of equal duration, is produced by applying a negative potential to the cable and is, therefore, drawn below the zero line. Thus, Fig. 28 represents a dot immediately followed by a dash, which forms the letter A.

Arrival Curve for Letter ***R.*** In Fig. 29 is shown the arrival curve for the combination, dot–dash–dot, or letter R, which is

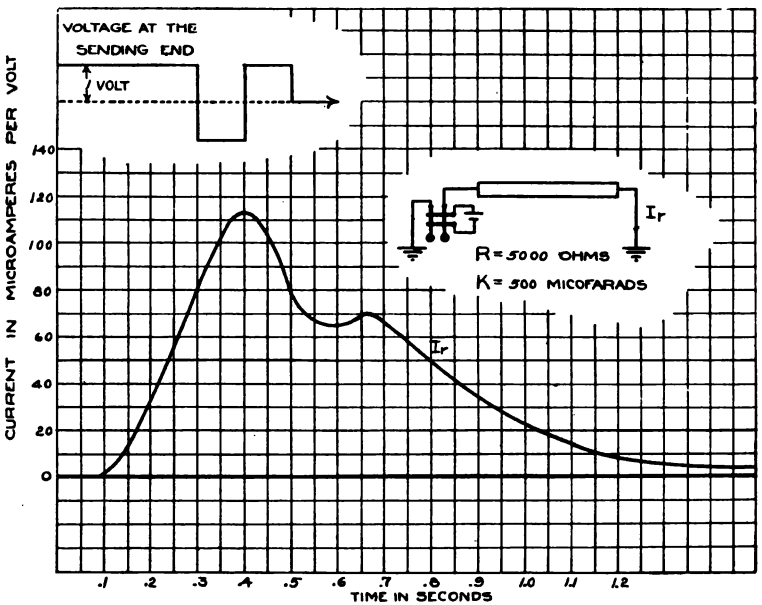


Fig. 30. Arrival Curve for "Understand" Signal "SN." Cable without Terminal Apparatus

formed, as previously explained, by properly extending the curve of Fig. 28. It will be noticed that the distortion is so great that the current pulse forming the dash does not even reach the zero line.

Arrival Curve for ***Understand*** *Signal.* The **understand** signal, used to separate all messages, is formed by the combination, 3 dots–dash–dot and, if the battery is applied for the duration of each dot or dash, as in the previous examples, the signal will arrive at the distant end of the cable as shown in Fig. 30.

It is evident that, as in the previous cases, there is a very considerable retardation and distortion of the signals which are transmitted through the cable. In fact, there is so much distortion that, if there were no means of overcoming it, the speed of sending would have to be reduced in order to read the signals. Beginning with the simple cases of the artificial cables and leading up to the real submarine cable it was seen that this retardation and distortion was caused by the distributed capacity and the resistance of the cable.

METHODS OF OVERCOMING DISTORTION

18. Use of Earthing Interval in Dots and Dashes. It is manifestly impracticable for an operator to send out by hand a combination of pulses as shown in Fig. 30 because he could not accurately time the duration of the three dots. However, this type of signal is found in some kinds of automatic transmission as will be explained later. Hence, in hand sending there is always an interval between dots and also an interval between dots and dashes. The interval between letters is made longer than this interval in order to distinguish between them. The interval between dots is a distinct advantage as the distortion is reduced by this earthing interval. This is brought out in the arrival curve for dot–dash (letter A) shown in Figs. 31 and 32. The total duration of a dot or dash is 0.1 second in each case but the earthing interval is different. In Fig. 31 the interval of earthing is 0.03 second, or 30 per cent of the total duration of the dot. In Fig. 32 the earthing interval is 0.05 second, or 50 per cent of the total duration of the dot.

These curves are built up from the Kelvin arrival curves in the same manner as before, care being taken to add the various Kelvin arrival curves at the proper time intervals. It is seen that the shorter the interval of applying the battery—interval of *marking*, as it is called—the smaller is the received current; however, its shape is better; that is, there is less distortion. Of course, this process of shortening the interval cannot be carried too far for the magnitude of the current would soon become too small to operate the receiving instrument. From 50 to 70 per cent marking has been found to give the best results.

In Fig. 33 is shown the **understand** signal when the marking is 70 per cent of the dot duration. It will be seen to have a slightly better shape than the signal of Fig. 30.

19. Curbed Signals. In the early days of cable telegraphy it was discovered that if a signaling pulse be followed immediately

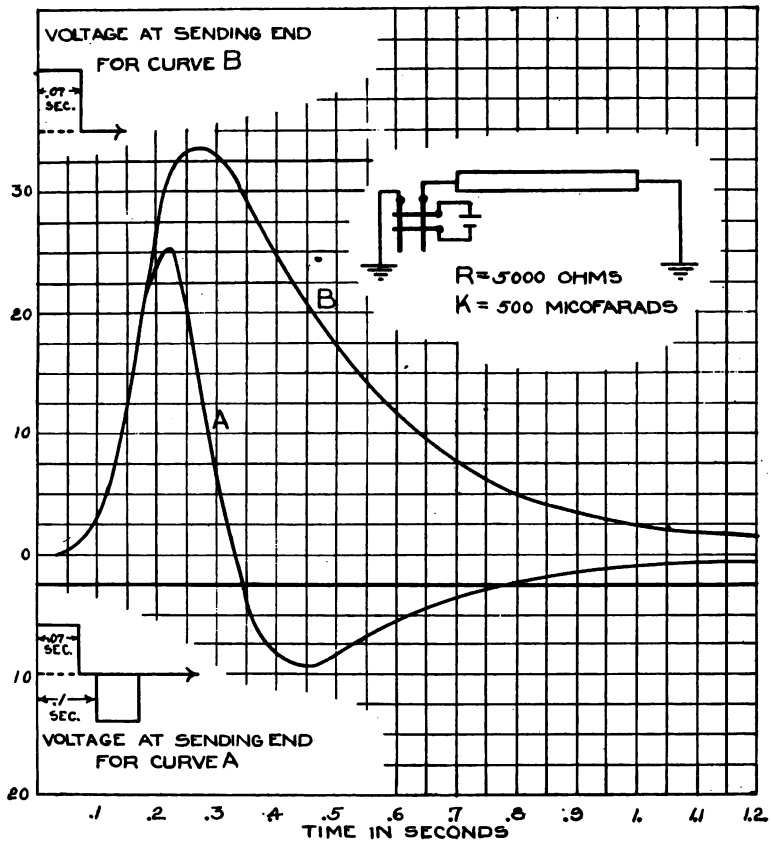


Fig. 31. Arrival Curves for Dot and Letter "A" When Using 70 Per Cent Marking

by a short pulse of the opposite sign, the signals at the receiving end are less distorted. Such a signal is called a **curbed** signal. The result of curbing applied to the **understand** signal is shown in Fig. 34. The length of this curbing pulse is three-tenths of the total length of the dot or dash. It will be seen that this signal is an improvement on those of Figs. 30 and 33. Further improve-

ment might be made by a curbing pulse of different length or by using a short earthing interval after the curbing pulse. However, other methods are usually employed for shaping the signals.

20. Signaling Condensers. It will be remembered that in charging a condenser by applying a battery through a resistance,

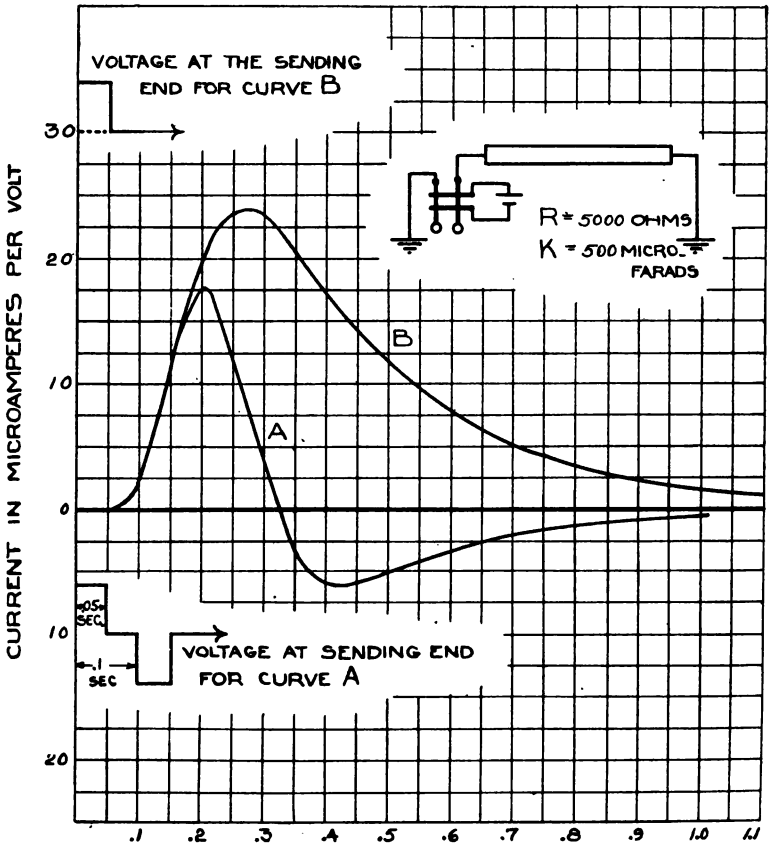


Fig. 32. Arrival Curve for Dot and Letter "A" When Using 50 Per Cent Marking

there is at first a large rush of current, which gradually decreases to zero as shown in Fig. 35. The current flowing through a condenser at any instant is directly proportional to its size and to the rate at which its potential is varying. Thus a condenser offers a large impedance to the flow of current when the applied potential varies slowly, and an infinite impedance when the applied poten-

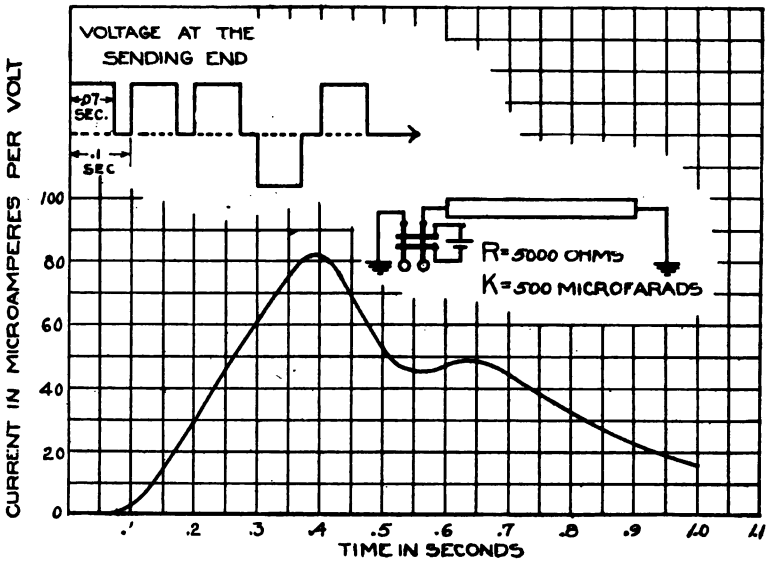


Fig. 33. Arrival Curve for "Understand" Signal When Using 70 Per Cent Marking, with No Terminal Apparatus

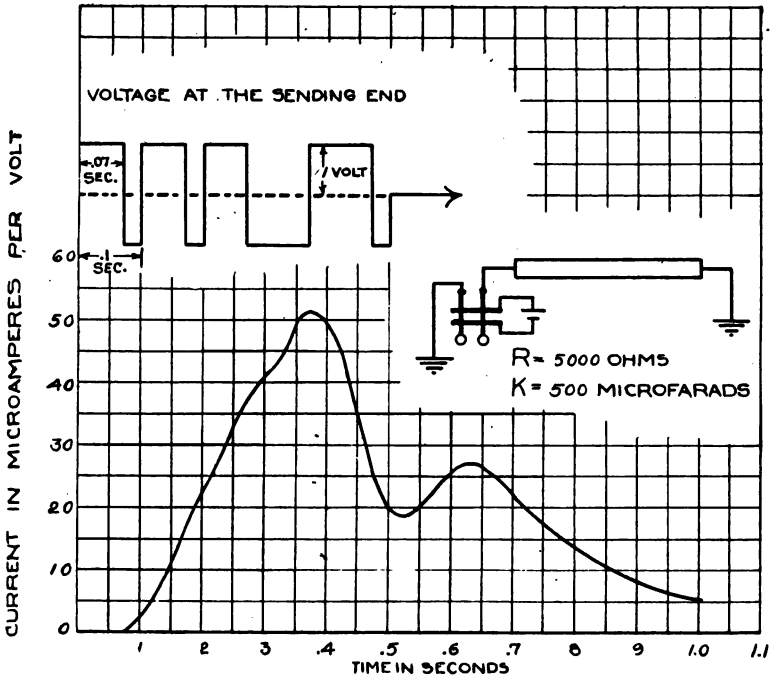


Fig. 34. Arrival Curve for "Understand" Signal. Curbed Signals, Cable without Terminal Apparatus

tial does not vary at all, at which point the current ceases to flow. If the applied voltage is not abrupt, as it is when a battery is suddenly connected to a circuit, but rises gradually to its full value there is no sudden rush of current.

Condensers Reduce Earth Currents. It was found that by connecting a condenser in series with a cable at either or both ends

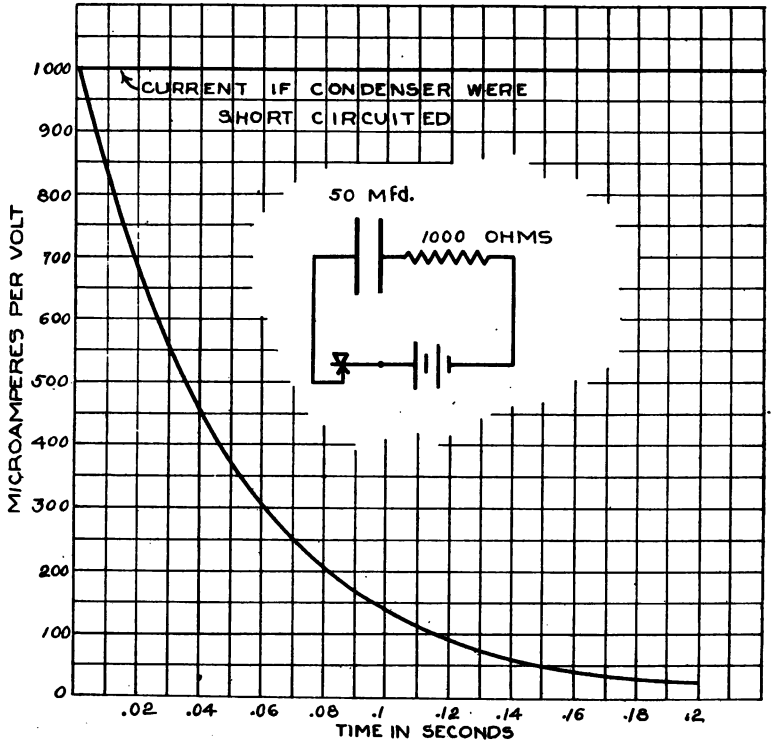


Fig. 35. Charging Condenser through Resistance

the parasitic currents—called *earth currents*—were usually reduced to a negligible size. These currents, which are apparently due to a difference of potential between different places on the earth's surface, generally vary slowly because this difference of potential varies slowly. Thus the condensers are effective in reducing these currents; in fact, without condensers the earth currents may become so large as to seriously interfere with signaling.

Action of Condenser. It was discovered that condensers made it possible to increase the working speed of the cable and the use

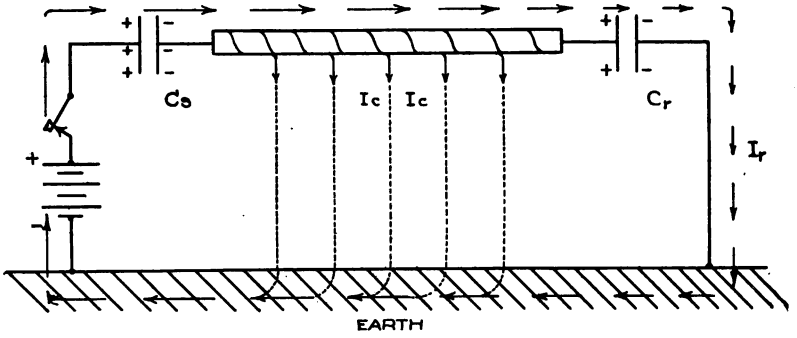


Fig. 36. Charging Condenser at Ends of Cable

of such signaling condensers soon became general. The cause of the improvement is not difficult to understand in view of the

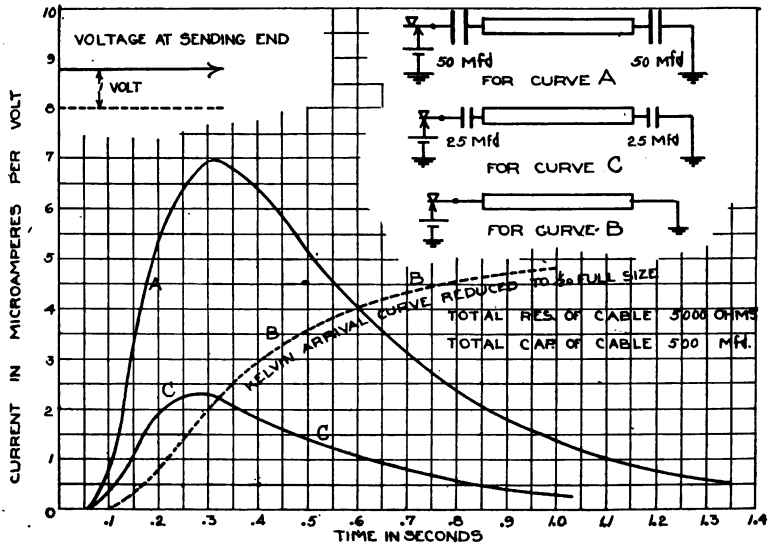


Fig. 37. Arrival Curve, Prolonged Application of Battery, Sending and Receiving Condensers

preceding discussion. Instead of the cable being charged continuously, as when a battery is applied directly to the cable, it receives a more or less sharp impulse through the condenser. The condenser charges rapidly, stops the flow of current into the

cable, and prevents the cable from getting the large charge it otherwise would. Since it is this slow charge and discharge of the cable which produces the great lag and distortion of the signals, the use of the condensers reduces this distortion, or in other words *sharpens* the received signals. It also reduces the amount of current but, if the condensers are not too small, the

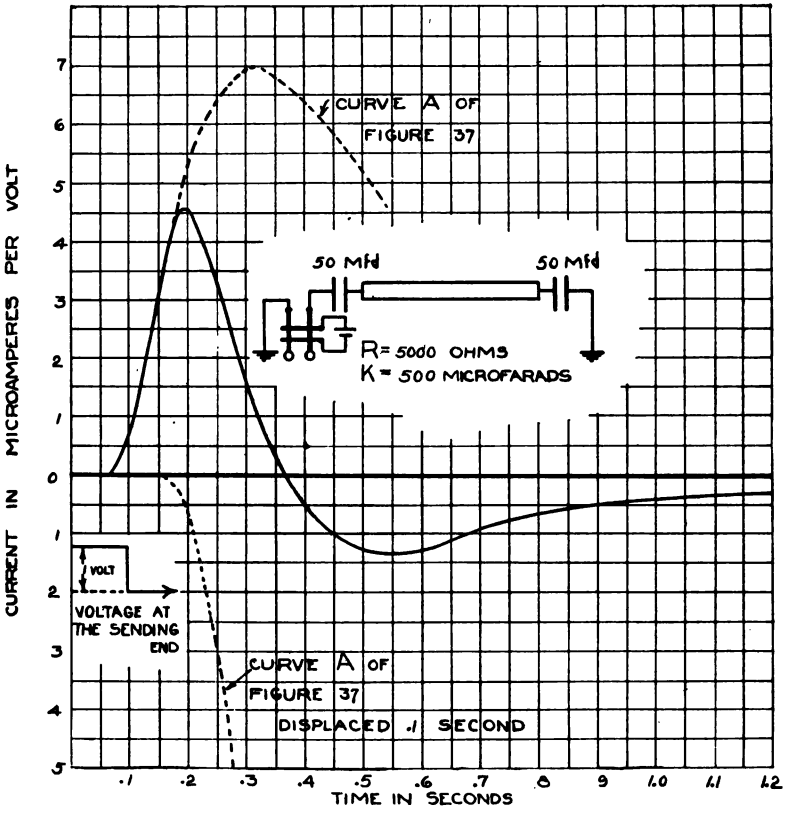

CURRENT IN MICROAMPERES PER VOLT
TIME IN SECONDS
CURVE A OF FIGURE 37
50 Mfd
50 Mfd
R = 5000 OHMS
K = 500 MICROFARADS
1 VOLT
VOLTAGE AT THE SENDING END
CURVE A OF FIGURE 37 DISPLACED .1 SECOND

Fig. 38. Arrival Curve for .1 Second Dot Sending and Receiving Condensers

received current will still be large enough to operate the receiving instruments. The process of charging the condenser at the two ends of the cable is shown in Fig. 36. The current I_c is the current which flows to charge the cable.

Arrival Curve for Prolonged Action of Battery. In Fig. 37 is given the arrival curve obtained when applying a battery to the

cable as shown in Fig. 36. The same cable constants are used as in the previous illustrations, and the capacity of each signaling condenser is 50 microfarads.

It will be noticed that the arrival curve *A* is much smaller and of different shape than the curve *B*, which is obtained when the battery is applied directly to the cable and which is here reproduced from Fig. 19 for comparison. The size and shape of the arrival curve will depend on the size of the condensers connected to any given cable. As the signaling condensers are made smaller and smaller the shape of the arrival curve is improved and the size reduced. There is a certain limit, however, beyond which any further reduction in the size of the condensers greatly

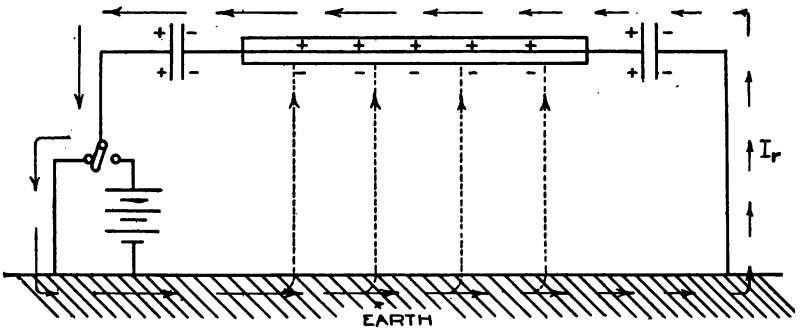


Fig. 39. Effect on Circuit of Removing Battery

reduces the size of the arrival curve without improving its shape very much. In practice the capacity of signaling condensers is about 0.1 the total capacity of the cable. Curve *A*, Fig. 37, is plotted for such a case, the signaling condensers being 50 microfarads each, or 0.1 the total capacity of the cable. When the signaling condensers are 0.05 the total capacity of the cable, the arrival curve *C* is obtained.

Arrival Curve for Single Dot. The shape of the arrival curve for a single dot or any combination of dots and dashes may be built up, in the case of a cable with signaling condensers, by using the arrival curve *A* of Fig. 37 just as the Kelvin arrival curve was used. Thus the arrival curve for a dot of 0.1 second duration may be built up as shown in Fig. 38.

It is seen that the arrival current for a single dot actually reverses direction. The main part of the dot arrival curve is above the line and, in practice, the small part of the curve below the line would not affect the proper reading of the signal. From Fig. 36 it will be seen how the signaling condensers become charged so that, when the battery is removed at the end of a dot, the dis-

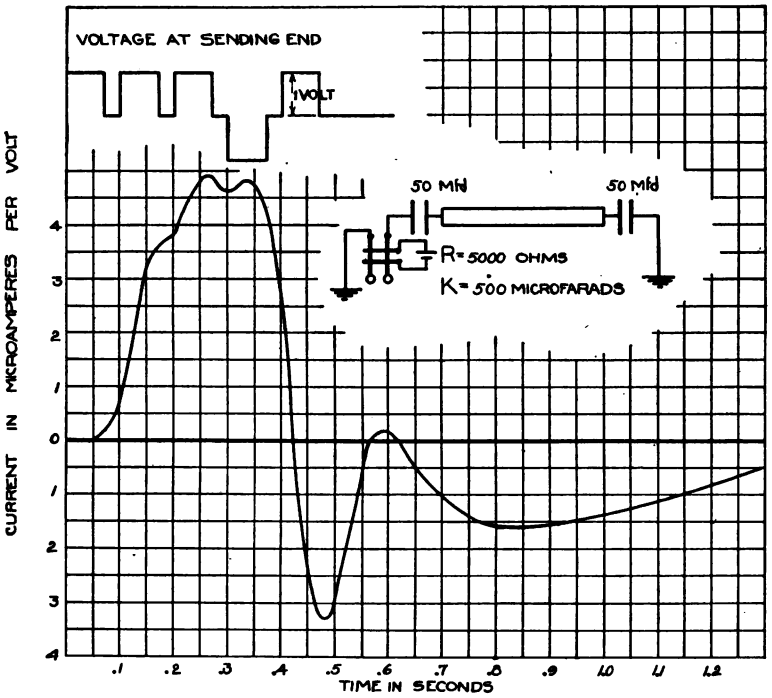


Fig. 40. Arrival Curve for "Understand" Signal with .1 Sending and Receiving Condensers

charging of these condensers produces a current at the receiving end in the opposite direction to that during charging, Fig. 39.

Arrival Curve for ***Understand*** *Signal with Condensers.* The arrival curve for the **understand** signal as built up from curve *A*, Fig. 37, using 70 per cent marking and 30 per cent earthing, is shown in Fig. 40. The arrival curve for the same signal when curbing each dot and dash element with a pulse of the opposite polarity of 0.3 the total dot length is shown in Fig. 41. In comparing this curve with the curves of Figs. 30, 33, 34, and 40, it

will be seen to what extent the distortion has been corrected by the use of signaling condensers and curbed signals. Even the curve, Fig. 41, shows considerable distortion as to the height of

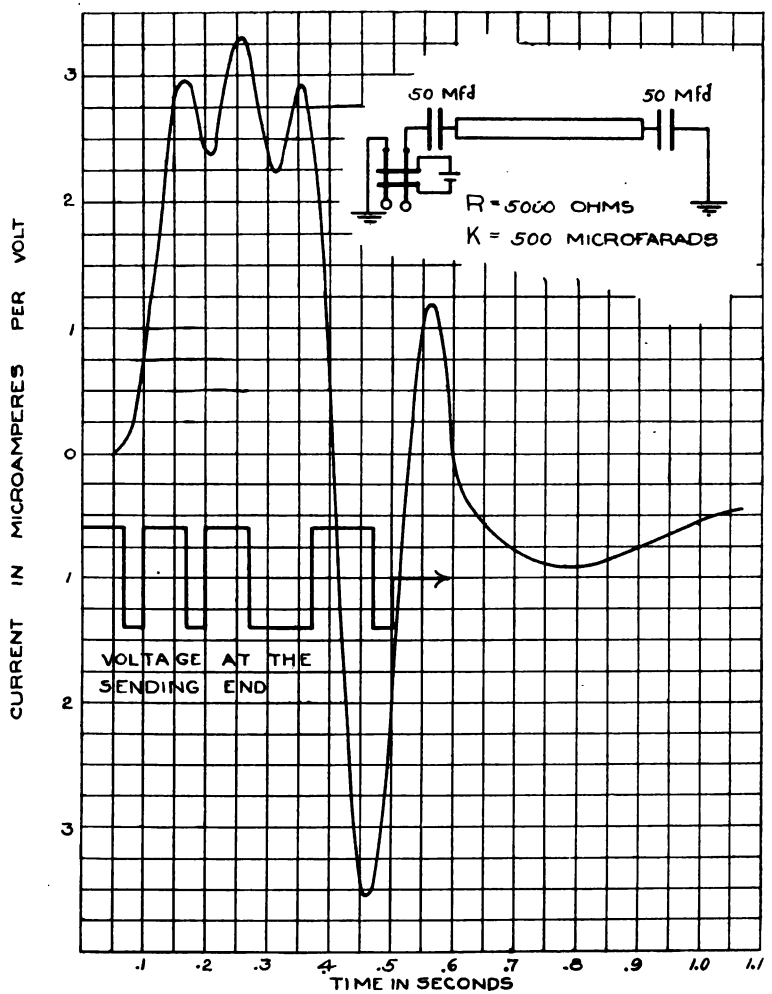


Fig. 41. Arrival Curve for "Understand" Signal. Curbed Signals, .1 Sending and Receiving Condensers

the different dots and dashes and as to their length, although it is far superior to the curve of Fig. 40, which corresponds to the more usual method of transmitting signals, with only a small earthing interval and not a reversed polarity for curbing purposes.

21. Magnetic Shunts. *Action of Shunt.* In order to further improve the signals over those received under conditions similar to those represented in Fig. 40, magnetic shunts are generally used. These are inductance coils having a high ratio of inductance to resistance. They may be placed around the receiving instrument, which is connected in series with the receiving condenser, or they may be placed around both the receiving instrument and the receiving condenser. (Methods of connecting the magnetic shunts for duplex operation are shown in Figs. 63 and 75.) It will be noticed that single dots or dashes last longer than the interval of the sending pulse and have a long "tail." This is more noticeable when two or more dots or dashes follow each other and when it causes the curve to rise, Fig. 40. Thus the signals have a large low-frequency component which distorts them. By offering a high impedance to the currents of *dot* frequency and a lower impedance to the lower frequency components of the signals, the magnetic shunts drain off a larger amount of these lower frequency components and hence greatly reduce the distortion. In order that such a curve as in Fig. 40 may be kept from rising above the average height of a dot, a shunt having a comparatively low value of inductance must be used. However, there must be enough resistance in the magnetic-shunt circuit to prevent too much of the very low frequency components of the received current from being drained through this shunt circuit. If the resistance of this shunt circuit is too low and too much of the very low frequencies are drained off, a sequence of dots or

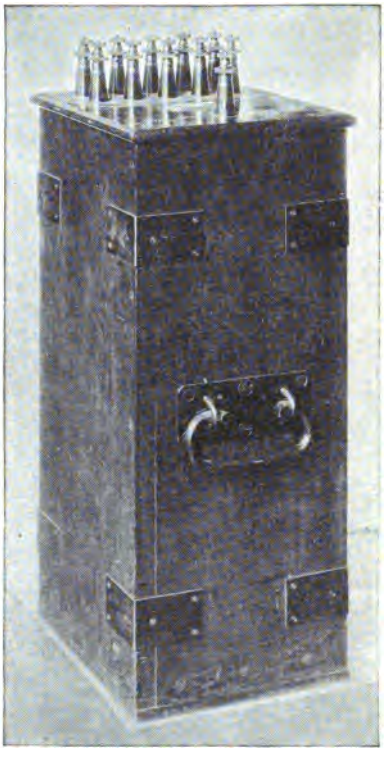


Fig. 42. Brown Type Magnetic Shunt

dashes would have a "falling off" characteristic instead of a "rising" characteristic, as in Fig. 40. This kind of distortion would also be detrimental to the formation of readable signals, and it is usually necessary to add a small resistance in series with the magnetic shunt to prevent this falling off of long sequences of dots or dashes.

Construction of Magnetic Shunt. Magnetic shunts are made by winding a coil of wire on an iron core, which may or may not have an air gap in it, and bringing out taps at various points. Since the current that flows through the coil is small—causing the magnetic flux density in the iron to be low and hence the magnetic permeability of the iron to be small—the iron core must be quite large in order to secure a high ratio of inductance to resistance. The copper wire of the coil must be fairly large to keep the resistance small. In Fig. 42 is shown a magnetic shunt which has a total inductance of 40 henrys and a total resistance of 30 ohms. By using the taps, 50 different values of inductance between 0.1 henry and 40 henrys may be obtained. This shunt is enclosed in a case 2 feet high and weighs about 150 pounds.

Effect on Signals. The actual effect of a magnetic shunt on signals is shown in the section on Duplex Transmission (Figs. 74 and 76). It is possible by this means to correct for the additional distortion caused by sending signals with 100 per cent marking (that is, *block* signals), although it will usually be found more difficult than to correct for signals with, say, 70 per cent marking.

22. Shunted Condensers. As previously explained, the receiving condenser is used in series with the receiving instrument in order to reduce the low-frequency components of the receiving current, just as the magnetic shunt is used around it for the same purpose. It has been found that when the inductance and series resistance of the magnetic shunt are given such values as to properly shape the first few dots or dashes of a succession of dots or dashes, any additional dots or dashes will "drop off," or become too small. In order to correct for this, a resistance shunt may be placed around the receiving condenser (see Fig. 69) which will admit enough of the latter part of the low-frequency current to keep the signals from "dropping."

It should be understood that the arrival curves of current which have been drawn in this section are not the exact curves

which would be traced by a siphon recorder on the same cable. On account of the inertia, the resistance, the inductance of the siphon recorder coil, and the presence of friction the curves traced will be somewhat different from the curves of the arrival *current*, but nevertheless the previous discussion should be of value in giving an idea of the effect of the various combinations of receiving apparatus on the signals.

SPEED OF SIGNALING

23. KR Law. The product of the total capacity and the total resistance of a cable is known as the KR of the cable, K representing the capacity, for which it was the old symbol, and R representing the resistance. This same product is sometimes designated by krl^2; wherein k and r are the capacity and resistance per nautical mile respectively, and l is the length of the cable in nautical miles. Both expressions yield the same numerical result since K equals kl and R equals rl, or KR equals krl^2. The numerical values of KR are usually given in farad-ohms. Thus, the cable we have been using for our examples has a capacity of 500 microfarads and a resistance of 5000 ohms, which means a KR of 0.0005×5000, or 2.5 farad-ohms, one farad being equal to 1,000,000 microfarads.

Retardation of Current Depends on KR of Cable. In the case of a cable *without any terminal apparatus*, what might be described as the retardation of the current forming the signals is dependent on the KR product alone. This can be expressed in another way by saying that the time required for the current at the distant end to rise to any *given percentage* of its full value varies directly with the KR of the cable. Therefore the arrival curve for a cable whose retardation is KR becomes the arrival curve for a cable having the same total resistance and a retardation of $K'R'$ by changing the time at all points of the original curve in the ratio of $\frac{K'R'}{KR}$. Thus, the arrival of curve Fig. 43, (reproduced from Fig. 19) for a cable whose KR is 2.5 ($R=5000$ ohms, $K=500$ microfarads) becomes the arrival curve for a cable whose KR is 5 ($R=5000$ ohms, $K=1000$ microfarads) by changing the time at each point to double the original value as shown.

Changes in Arrival Curves with Unequal Resistances. In order that the arrival curve for a cable whose retardation is KR and resistance R may become the arrival curve for a cable whose retardation is $K'R'$ and resistance R', the height of the original curve must be changed at each point in the ratio of $\frac{R}{R'}$ in addition to changing the time for each point of the curve as previously specified. Thus, in order to obtain the arrival curve for a cable whose total capacity is 750 microfarads and total resistance 10,000 ohms ($KR=7.5$) from the arrival curve for a cable whose

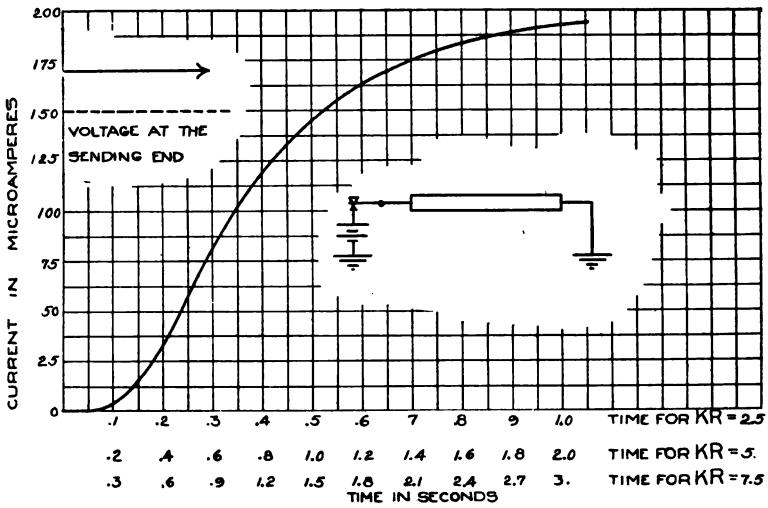

200
175
150
125
100
75
50
25
0
CURRENT IN MICROAMPERES
VOLTAGE AT THE
SENDING END
.1 .2 .3 .4 .5 .6 7 .8 9 1.0 TIME FOR KR = 2.5
.2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 TIME FOR KR = 5.
.3 .6 .9 1.2 1.5 1.8 2.1 2.4 2.7 3. TIME FOR KR = 7.5
TIME IN SECONDS

Fig. 43. Kelvin Arrival Curve with Prolonged Application of Battery, for Cables Having Various KR Values; Applied Voltage in Each Case Having Such Value That Final Steady Current Will Be 200 Microamperes

total capacity is 500 microfarads and total resistance 5000 ohms ($KR=2.5$), the time at each point on the latter curve would have to be multiplied by three $\left(\frac{7.5}{2.5}\right)$ and the height of the curve would have to be made one-half $\left(\frac{5000}{10000}\right)$ as great. It is evident that the final steady current in a circuit of 10,000 ohms resistance would be only one-half as large as in a circuit whose resistance is 5000 ohms, and the same is true for the transient part of the arrival curve.

Changing Voltage to Adjust Arrival Curves. The preceding statements are made on the assumption that the applied voltage is the same in each case. If the applied voltage were changed in the ratio of $\frac{R'}{R}$, the height of the curve would not need to be changed and the various arrival curves would coincide by merely changing the value of the time at each point in the ratio of $\frac{K'R'}{KR}$. This is the usual assumption made when comparing the speeds at which cables can be operated. Accordingly, if in the example given the voltage were made one-half as great on the 5000-ohm 2.5–KR cable as on the 10,000-ohm 7.5–KR cable, it is evident that the received current on the 2.5–KR cable would always reach the same value as that on the 7.5–KR cable in one-third of the time; or, the length of time necessary to form similar signals on the former cable would be one-third as great as that necessary on the latter cable. If it took 0.1 second to form dots or dashes on the former cable and 0.3 second to form dots or dashes of equal size on the latter cable, the speed of signaling would be three times as great on the former cable as on the latter, since the speed of signaling varies inversely as the time necessary to form the signals.

In general, *when the voltages are changed in the proper ratio, the speed of signaling is inversely proportional to the KR of the cable.* This is known as the KR law and was originally stated by Lord Kelvin. It presupposes that the cables are without leakage and that both ends of the cable are to earth, without sending or receiving apparatus other than a key and a battery. Therefore, if this law is used to estimate the relative speeds of cables under working conditions, that is, with sending and receiving apparatus, a considerable error is likely to be made. The generalization of the law to conform to these conditions is given in the succeeding sections.

24. Generalized *KR* Law. The above method of assuming variations in time, voltage, etc., until the arrival curves for different cables are the same and then comparing the length of time necessary to form signals of equal size and shape is the method usually followed in comparing the relative operating speeds of cables. Following this method, Malcolm has extended

the KR law to apply to certain cases in which terminal apparatus is used, as follows:

Two cables will transmit signals of the same *shape*, provided

$$\frac{r'l'}{rl}=\frac{kl}{k'l'}=\frac{gl}{g'l'}=\frac{L'l'}{Ll}=\frac{Z_s'}{Z_s}=\frac{Z_r'}{Z_r}=m \qquad (11)$$

wherein l and l' are the lengths of the cables in nautical miles; r and r' are the resistances of the cables in ohms per nautical mile; k and k' are the capacities of the cables in microfarads per nautical mile; g and g' are the leakage conductances of the cables in ohms per nautical mile; L and L' are the self-inductances of the cables in henrys per nautical mile; Z_s and Z_s' are the impedances of sending apparatus in ohms; Z_r and Z_r' are the impedances of receiving apparatus in ohms; and m is the numerical value of the ratios represented in the left-hand members of the equation. Furthermore the *size* of the signals will be in the ratio of $\left(\frac{rl}{r'l'}=\frac{1}{m}\right)$ if the same voltage is used, or their size will be the same if the sending voltages are in the ratio of m to 1.

It is usual to assume that L and g are zero for submarine cables. It will be seen from equation (11) that this law applies only to cables having the same values of krl^2 and hence having the same speed, which greatly limits its application.

Practical Adjustments of Law. It usually happens in practice that the constants and the terminal apparatus of the two cables which we wish to compare will not satisfy equation (11). In such cases the arrival curves may still be "matched" for the purpose of comparing speeds if the terminal apparatus is simple and if there is a certain relation between a few of the constants. The equations showing these relations for various arrangements of terminal apparatus are given in more advanced texts. If there is a capacity alone at each end of the cables and if the values of these capacities are such that

$$\frac{K_s}{kl}=\frac{K_s'}{k'l'}$$

and

$$\frac{K_r}{kl}=\frac{K_r'}{k'l'}$$

we need only multiply the time at each point of the arrival curve

for the cable whose retardation is krl^2 by $\frac{k'r'l'^2}{krl^2}$ and assume the applied voltage to be changed in the ratio of $\frac{r'l'}{rl}$ to have the curve become the arrival curve for the cable whose retardation is $k'r'l'^2$. Thus, when the ratio of the capacities of the sending and receiving condensers to the total capacity of the cable is the same for several cables, their speeds of signaling are inversely proportional to their KR values and the KR law still applies.

Comparing Speeds of Cables. Let us compare the speed of the following cables:

Cable No. 1

$l = 1500$ n.m.
$r = 3\frac{1}{2}$ ohms per n.m.
$k = \frac{1}{4}$ mfd. per n.m.
$K_s = K_r = 50$ mfd.
$krl^2 = 2.5$ farad-ohms
$rl = 5000$ ohms
$kl = 500$ mfd.
Speed = 200 letters per minute

Cable No. 2

$l' = 2500$ n.m.
$r' = 2.4$ ohms per n.m.
$k' = 0.25$ mfd. per n.m.
$k'r'l'^2 = 3.75$ farad-ohms
$r'l' = 6000$ ohms
$k'l' = 625$ mfd.
$K'_s = K'_r = 62.5$ mfd.

From the data for cable No. 1 we see that

$$\frac{K_s}{Kl} = \frac{K_r}{Kl} = \frac{50}{500} = \frac{1}{10}$$

Also for cable No. 2 we have

$$\frac{K'_s}{k'l'} = \frac{K'_r}{k'l'} = \frac{62.5}{625} = \frac{1}{10}$$

Therefore the ratio of the retardations of the two cables is

$$\frac{k'r'l'^2}{krl^2} = \frac{3.75}{2.5} = 1.5$$

Now if the voltage on cable No. 2 were made $1.2\left(\frac{6000}{5000}\right)$ times as great as that on cable No. 1, the received current on cable No. 2 would always arrive at the value it has on cable No. 1 in 1.5 times as long a period from the instant of applying the battery as it takes to arrive at this value on cable No. 1; that is, the speed of signaling will be $\left(\frac{1}{1.5}\right)$, or $\frac{2}{3}$ as great on cable No. 2 as on cable No. 1, or 133 letters per minute.

Additional Conditions when Terminal Apparatus Has Resistance and Capacity. When the terminal apparatus has resistance only or resistance and capacity, certain other ratios must be equal in order that the KR law may apply. It very often happens that these ratios are not equal on cables which we wish to compare; in this case, the only way remaining to theoretically compare their speeds is to independently calculate some arrival curves for each of the cables at a number of speeds. By comparing these curves one can find their relative speeds.

The preceding methods of comparing the speeds of different cables are based entirely on the arrival current and do not take into account the sensitivity of the receiving apparatus, which consists of some form of galvanometer, recorder, or relay. It has been assumed that the sensitivity is the same in all cases regardless of the speed of operation, which, of course, is not ordinarily true. For example, if any given recorder is adjusted to give the largest possible signals at 200 letters per minute, it will not give as large signals at 250 letters per minute if the received current is *no larger* than it was at 200 letters per minute. The higher the speed, the *larger* the current required to give signals of the same size on the recording device, not the *same current* as was assumed when using the KR law to compare speeds. The exact amount of increase in current required to operate at higher speeds depends on the receiving device and its adjustment.

25. Speed Constant of Cables. It is due largely to the change of sensitivity of the receiving apparatus with speed that the increase of speed of a low KR cable, when estimated from that of a higher KR cable, is not as great as indicated by the KR law, and vice versa. However, the KR law is probably the best method we have of getting the approximate speed of a cable. It will be seen that if the speed follows this law and varies inversely as the KR of the cable as indicated in formula (12), the product of the speed and the KR of a cable will be a constant for all KR values. This constant is known as the speed constant.

$$\frac{S'}{S} = \frac{KR}{K'R'} \tag{12}$$

or

$$KR \times S = K'R' \times S' = \text{constant} \tag{13}$$

wherein S is the speed on a cable whose retardation is KR; and S' is the speed on a cable whose retardation is $K'R'$. When this constant is derived for any given cable from the actual speed and the known KR value, it includes every condition of working, such as applied voltage, sending and receiving condensers, sensitiveness of the receiving instrument, amount of curbing, skill of the operators in reading signals, etc. If these conditions are changed the constant will not have the same value. Thus, when estimating speeds which are widely different, it is customary to use a different speed constant in order to take account of the variation in sensitiveness of the receiving instrument with speed, as pointed out before, and to then apply the KR law within a limited range. Of course, the sensitiveness of the receiving instrument, and therefore the speed constant, depends on the type of instrument as well as on the speed at which it is operated. The speed constant for duplex working—using a 50-volt battery and a Muirhead siphon recorder as the receiving instrument—is about 500 for cables having a KR between 2 and 3 farad-ohms, the speed being given in letters per minute. Thus

$$S = \frac{500}{KR} \text{ letters per minute} \qquad (14)$$

It is evident from the preceding discussion why it is so desirable to use the shortest route in laying a cable between two places, since the KR for a core of a given size increases as the square of the length with a consequent reduction in speed. For the same reason a cable between two distant points is, if possible, cut into two sections, each of which can be worked at a much higher speed than could the cable as a whole. Thus, cutting a cable into two equal sections would reduce the KR of each section one-fourth the KR of the whole cable, making the theoretical speed of each section four times the speed of the whole cable worked as a single section. The actual increase in speed working in sections would not, of course, be this large, as previously explained.

It is for the reason just stated that nearly all the Atlantic cables from New York to British points are cut into Newfoundland, the most easterly point of North America, and terminated at the most westerly point of Ireland, thus dividing the cables as nearly as possible into two equal sections.

DUPLEX CABLE TELEGRAPHY

26. General Arrangement. Duplex telegraphy, or the transmission of messages over an electrical circuit in both directions at the same time, is made possible by so arranging the receiving instruments that, while responding to signals from the distant end of the circuit, they do not respond to signals sent into the end of the circuit at which they are located. Since the capability of the cable for handling messages, and hence its earning capacity, is greatly increased by this means, most submarine cables are now duplexed. There are several methods of duplexing, all of which

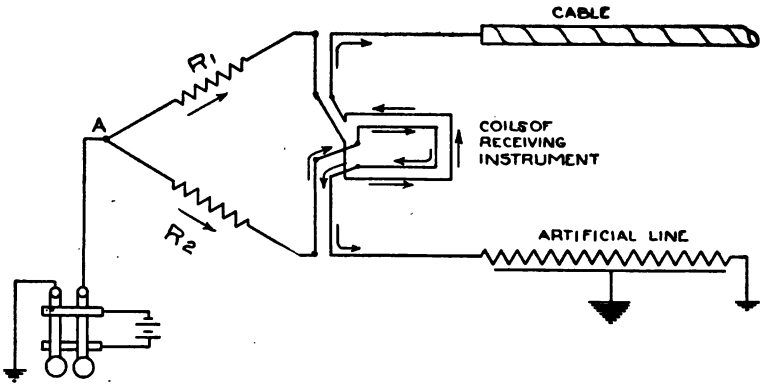


Fig. 44. Differential Duplex. Positive Pole of Battery to Cable at Home End, Distant End of Cable to Earth

depend on the use of an artificial cable. This artificial cable—usually called the artificial line—should be as nearly as possible like the real cable in resistance and capacity in order to secure the best results.

27. Differential Duplex. The differential method of duplexing was the first to be applied to a short section of an Atlantic cable; it was employed by Mr. J. B. Stearns in 1873, using a Varley type of artificial cable. The coil of the receiving instrument had two separate windings of an equal number of turns, connected as shown in Fig. 44. One winding is connected in series with the resistance R_1 and the main cable, while the other winding is connected in series with the resistance R_2 and the artificial cable.

Signaling from Home End. When the key at the home end is operated, the current divides at junction A and flows through these two windings in opposite directions. When the resistances R_1 and R_2 are equal and the artificial cable is electrically equivalent to the real cable, the current will divide equally at A, so that its magnetic effect on the coil of the receiving instrument is zero. The receiving instrument will therefore not respond to signals sent from the home end.

Signaling from Distant End. The current from the distant end flows into the windings of the receiving instrument as shown in Fig. 45. It will be noticed in this case that the currents in the two windings are in the same direction and therefore, as their

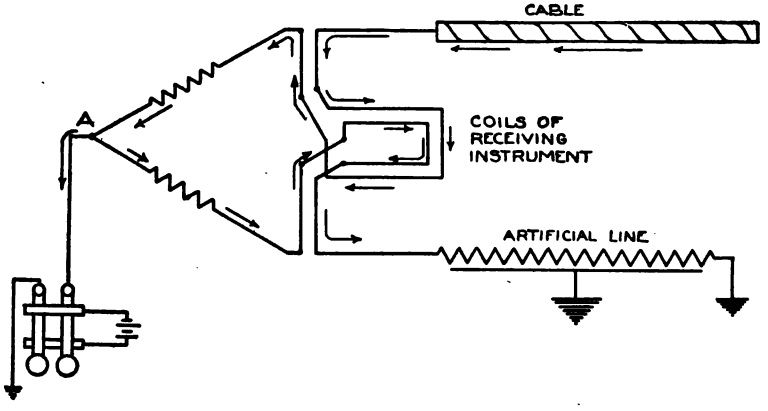


Fig. 45. Differential Duplex. Home End of Cable to Earth, Positive Pole of Battery to Cable at Distant End

magnetic effects are additive, they operate the receiving instrument. If the resistance from A to ground is zero, no current will flow in the winding connected to the artificial cable and the receiving instrument will be operated by the current in only one winding.

When the battery is applied to both ends of the cable simultaneously, the resulting current in any part of the circuit will be the algebraic sum of the currents that would be produced by each battery separately; therefore the effective current and the total magnetic action in the coil will be the same as though only the distant battery were applied, and the receiving instrument will still respond only to signals from the distant end.

28. Bridge Duplex. The bridge method of duplexing is the one now almost universally employed. In this method the principle of the Wheatstone bridge is used as shown in Fig. 46, which illustrates the earliest method of applying the bridge duplex to a cable, using resistance arms R_1 and R_2.

If the artificial cable is exactly similar to the real cable (that is, has the same electrical constants) and the resistances R_1 and R_2 are equal, the current from the home battery will divide equally at the junction A as shown by the arrows. Hence the drop in potential between A and B will be the same as between A and C, and, points B and C being at the same poten-

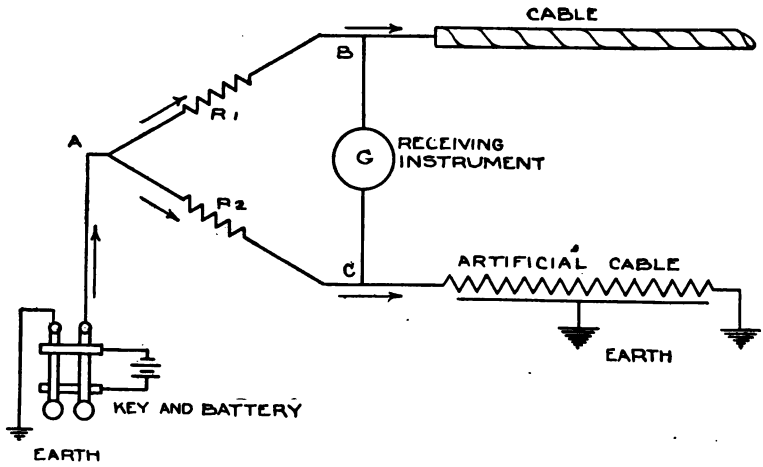


Fig. 46. Bridge Duplex. Resistance Ratio Arms R_1 and R_2. Positive Pole of Battery to Cable at Home End, Distant End of Cable to Earth

tial, no current will flow through the receiving instrument G. If the battery is applied to the distant end alone, current will flow through the receiving instrument G as shown in Fig. 47.

When batteries are applied simultaneously at both ends, the current through the home-end receiving instrument is controlled by the battery at the distant end and is the same as if that battery alone were connected, thus securing the reception of signals independently of those being sent.

29. Muirhead Double-Block Bridge Duplex. In the bridge duplex method just described the ratio arms of the Wheatstone bridge are formed by resistances R_1 and R_2. As a similar arrange-

ment is used at the other end of the cable, one of these resistances is in series with the main cable at each end, and because

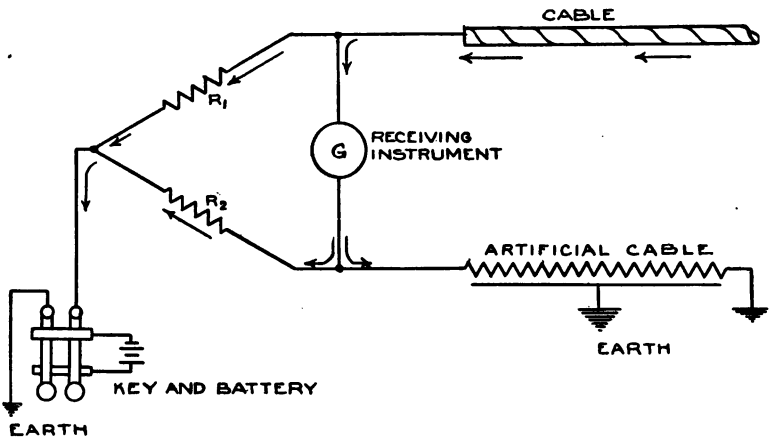


Fig. 47. Bridge Duplex. Resistance Ratio Arms, Home End Earthed and Positive Pole of Battery to Cable at Distant End

of the increased lag in the current and the consequent distortion of the signals resulting, the speed of operation is materially reduced. For this reason and because of the prevalence of earth currents on some cables, the use of condensers for the bridge arms

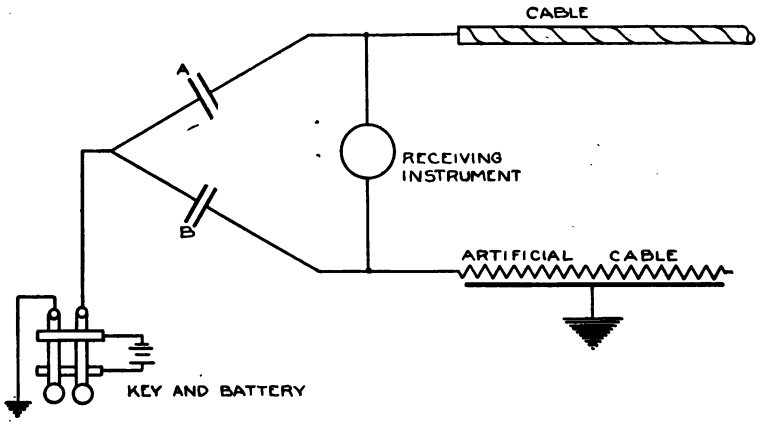


Fig. 48. Muirhead Double-Block Bridge Duplex

has come into general use. This method of forming a bridge duplex, shown in Fig. 48, is known as Muirhead's *double-block*

method and was patented by J. and A. Muirhead in 1876. It is the method used on most cables at the present time.

The use of condensers for the bridge arms not only permits doing away with injurious resistances at the ends of a cable but substitutes in their places capacity impedances, which makes the signals better than they would be if received over a cable free of terminal apparatus and put directly to earth at both ends. This was pointed out in a previous section and can be seen by a comparison of the curves of Figs. 34 and 41. Thus the necessity of having some kind of impedance to form the bridge arms is turned to a positive advantage.

The best results as to shape and size of signals are usually secured when the condensers A and B, known as the *block condensers*, each have a capacity equal to about one-tenth of the total capacity of the cable.

ARTIFICIAL CABLES

30. Necessary Conditions. In both the differential and the bridge duplex systems it is necessary, in order to secure good duplex operation, to have an artificial cable which possesses approximately the same electrical properties as the main cable. This is because the current flowing into the artificial cable must be approximately equal to that flowing into the main cable at each instant after the closing of the key; furthermore the discharge currents must be the same at each instant after grounding the cable. This is equivalent to saying that the artificial cable must offer the same sending-end impedance to currents of all frequencies as the main cable.

TYPES

31. Stearns Type of Artificial Cable. There are three types of artificial cables designed to meet the conditions just stated. One type, similar to those described in a previous section and illustrated in Fig. 49, consists of a resistance divided into sections to represent the conductor and a capacity to ground between each section. This type, in which each section of capacity and resistance is separately adjustable—known as a *lumped* line—was used by Stearns in duplexing a short section of one of the "Anglo"

Atlantic cables in 1873, the first material length of cable to be duplexed. It was first described and patented by Mr. C. F. Varley in 1862 for a different purpose and had to be greatly improved before it was of use in duplexing cables.

Comparison of Two- and Four-Section Artificial Cables with Real Cable. In order to simulate the sending-end characteristics of a real cable, an artificial cable of this type must be made up of a large number of sections. To illustrate this, curves showing the current flowing into the sending ends of artificial cables made up of two sections and four sections are plotted with curves showing the current flowing into the sending end of a real cable, Fig. 50. The cable used for this example has the same constants as the one used in previous examples (5000 ohms and 500 microfarads), and the various artificial cables have the same resistance and capacity as the real cable. A study of the curves will show that, as we pass from two to four sections, the current flowing into the artificial cable due to a prolonged application of battery becomes more nearly the same, at all instants, as the current flowing into the real cable.

Difficulties with Artificial Cables. It will also be noticed that even with a cable of four sections the difference between the sending current and that for a real cable is at times more than 25 microamperes per volt. This would cause far too much disturbance for duplex working, since the received current on such a cable would be only 1 or 2 microamperes per volt at ordinary working speeds. Indeed, it would be necessary to have an artificial cable of hundreds of sections in order to successfully duplex this cable. Furthermore, the sending-current curves would have to be drawn to a scale many times larger than those

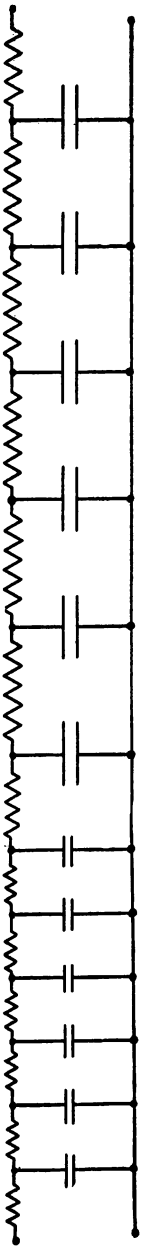


Fig. 49. Stearns Type of Artificial Cable. Capacity and Resistance of Each Section Adjustable

of Fig. 50 to detect the difference between the sending currents into the real and the artificial cables which would be just sufficient to affect the sensitive receiving instruments. It is this great difference between the current going into the cable and the current received from the cable that makes it necessary to have an artificial cable so nearly like the real one when duplexing long submarine cables, since it only requires such an extremely small fraction of the large sending current to completely obscure the received current. On land lines the current does not suffer nearly as great attenuation as on long cables and the artificial line does not need to be so nearly like the real line. In fact, land lines are successfully duplexed with an artificial line of several sections (usually two or three sections), but much greater precision is required in duplexing an ocean cable.

Effect of Leaving Distant End of Cable Open. In Fig. 50 is also shown the sending current I_s' which flows into the real cable when the distant end is open. It is seen that there is no appreciable difference between this current and the sending current I_s which flows when the distant end is earthed until after a certain lapse of time—0.4 second in this case—although this is the most radical change which would be made at the distant end.

Other Variations in Cable. Other less radical changes, such as the insertion of resistance or a condenser between the distant end of the cable and earth, would cause still less difference between the sending currents. It can be shown that the point of time at which any given change in the arrangement of the capacity of an artificial cable begins to influence appreciably the sending current depends on how far from the sending end of the cable the change is made. Changes in the arrangement of the capacity near the sending end of the cable make themselves felt in the sending current very quickly after the key is closed and vice versa. As will be explained later, the receiving instruments are especially sensitive to rapidly varying currents and are made insensitive to slowly varying currents by the use of magnetic shunts and series condensers, so that any inequality between the currents flowing into the sending ends of the main and the artificial cables which comes in gradually after a certain lapse of time will be quite large before it will interfere with the receiving

instrument. For this reason the subdivisions of the artificial cable can be made larger in size and fewer in number as their distance from the sending end of the cable increases.

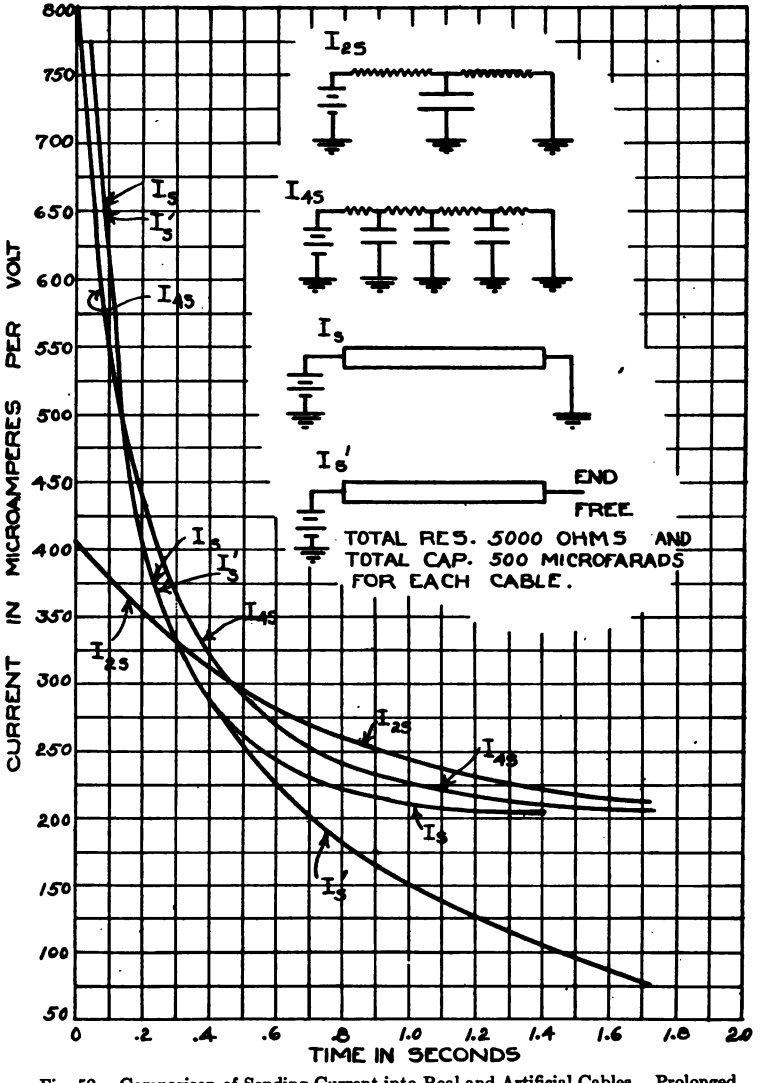


Fig. 50. Comparison of Sending Current into Real and Artificial Cables. Prolonged Application of Battery

Just after the key is closed and the voltage at the sending end is changing rapidly in a manner determined by the char-

acteristics of the cable near the sending end is the time when closeness of approximation between the main and the artificial line currents is most desired. For this reason the first part of the artificial cable must be made up of a large number of small subdivisions in order to imitate to the desired degree of accuracy the "smooth" distribution of capacity in the real cable, and also to secure that other essential of an artificial cable—the same ratio of capacity to resistance at each point as has the imitated real cable at corresponding points. It will be seen that an artificial cable of this type is quite flexible and capable of very close adjustment because of the large number of points at which the value of the capacity can be changed. It is subject however to the disadvantage that some variation of contact resistance and leakage is likely to occur in the large number of connections.

32. Muirhead Type of Artificial Cable. Owing possibly to faulty construction, poor materials, or the use of too large subdivisions the first artificial cables of the type used by Stearns in 1873 were not found suitable for duplexing the long cables across the Atlantic, where the greatest accuracy is required. Consequently for many years the type of artificial cable used in duplexing all the long cables was that known as the *inductive resistance* type (combining resistance and capacity in one), patented in 1875 by Taylor and Muirhead.

Construction. This type of artificial cable was known as a "smooth" cable in distinction from the "lumped" type just described and was made up as shown in Fig. 51. A sheet of tinfoil *a* is cut so as to make a number of zigzag strips and another *solid* sheet of tinfoil *b* laid under this and insulated from it by one or more sheets of paraffined paper. The zigzag strips of tinfoil represent the cable conductor; the solid sheets of tinfoil represent the sheath and water around the cable conductor; and the paraffined paper represents the gutta-percha insulation between the conductor and the sheath. The current flows, as shown by the arrows, through the zigzag conductor, there being a certain amount of electrostatic capacity between it and the solid tinfoil sheet, just as there is between the core and sheath of a real cable.

Determining Constants of Artificial Cable. The resistance of the artificial cable is determined by the dimensions and composi-

tion of the zigzag strips and its capacity is determined by the dimensions of the strips and the thickness and specific inductivity of the dielectric (paraffined paper). Thus the proper ratio between resistance and capacity to simulate any given cable can be secured by varying the width of the tinfoil strips or the thickness of the paraffined paper.

Two sheets of tinfoil like *a* and *b* could be made to represent an entire cable if they could be extended sufficiently, but in order to make such a cable compact enough to be practicable it is necessary to use a number of sheets cut into short lengths and arranged in alternate layers, Fig. 51, always having an *earth* sheet on each side of a *conductor* sheet. Thus, the two sheets *a* and *b*

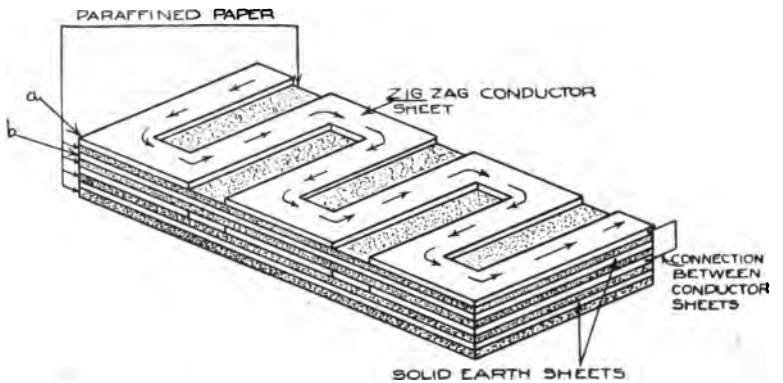


Fig. 51. Schematic Diagram of Muirhead Type of Artificial Cable

form one element of the artificial cable. The zigzag sheets are connected together in sequence, so that after the current circulates through one such sheet, it passes into the next zigzag sheet and circulates through it, and so on, Fig. 51. Connections are brought out to terminals from these zigzag *conductor* sheets at varying intervals—at short intervals in the first part of the cable and at longer intervals in the latter part, as shown in Fig. 52. The zigzag line from M to N represents a number of zigzag sheets connected as described, and the straight line beneath it represents an equal number of solid *earth* sheets. The solid sheets associated with any section of cable, as $M-N$, are connected together and a connection brought out to an earth terminal.

These terminals are connected to earth when the artificial cable is in use. The earth sheets are sectionalized so that if, in the final adjustment of the artificial cable, the ratio of capacity to resistance is too large, the capacity of certain sections between

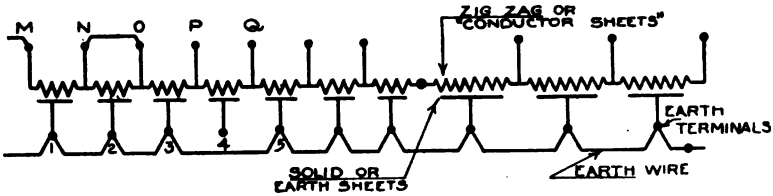


Fig. 52. Schematic Diagram Showing Methods of Adjusting Muirhead Artificial Cable

conductor and earth may be eliminated and the resistance left by taking the earth connection from the earth terminals, as section 4, Fig. 52.

Methods of Varying Capacity and Resistance. Since, however, the capacity is so intimately associated with the resistance, the removal of the earth wire from terminal 4, Fig. 52, while eliminating any capacity between the conductor *P–Q* and earth, leaves capacity shunting the conductor *P–Q;* that is, the circuit from *P* to *Q* is approximately equivalent to that shown in Fig. 53, so that some of the current flowing from *P* to *Q* will flow into the earth plate from the first part of the conductor and again out of the earth plate back into the latter part of the conductor. Thus a type of circuit entirely unlike the real cable is created.

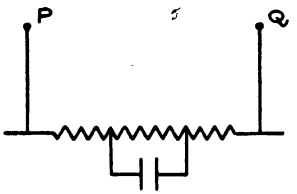


Fig. 53. Circuit Approximately Equivalent to Section P-Q of Fig. 52

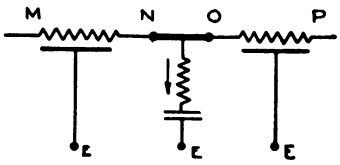


Fig. 54. Section N-O, Approximately Equivalent to Section N-O of Fig. 52

Similarly, if the ratio of capacity to resistance is too small, the resistance of a section may be cut out and the capacity left by connecting the conductor terminals at the ends of this section, as section *N–O*, Fig. 52. This will introduce a large lump of

capacity at this point and increase the average ratio of capacity to resistance. Since the resistance is distributed, it cannot all be eliminated by this method and the current will flow from both points *N* and *O* into these earth sheets *through some resistance.* The approximately equivalent circuit is shown in Fig. 54. Both

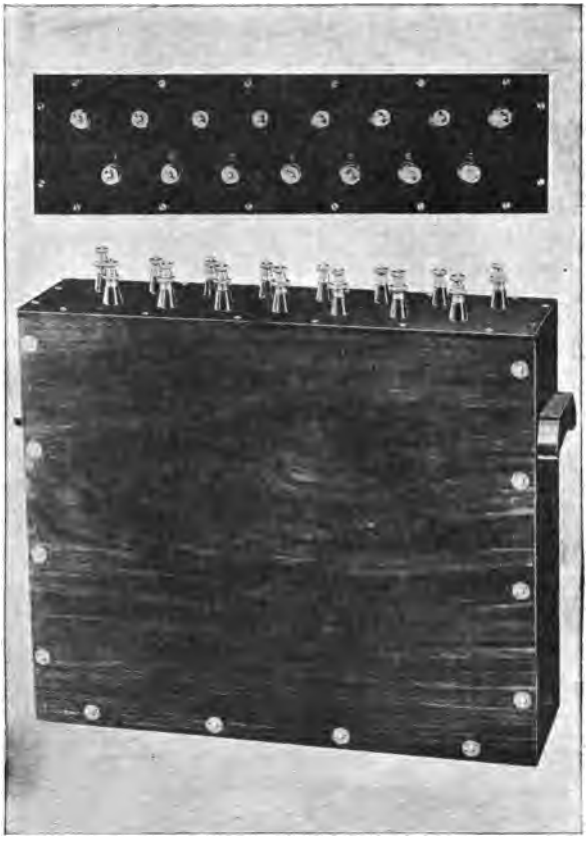


Fig. 55. Muirhead Zig-Zag Type of Artificial Cable Enclosed in Hardwood Case

of these methods of changing the ratio of capacity to resistance, in addition to creating types of circuits having no equivalents in the real cable, introduce comparatively large lumps of capacity or resistance, thus losing some of the benefit resulting from the extremely uniform distribution of capacity.

Practical Form of Artificial Cable. Artificial cables of the Muirhead type are put up in wooden boxes, Fig. 55, in which they are embedded in a good heat insulator. There is greater

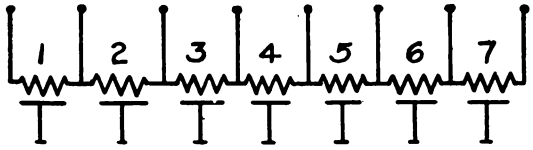


Fig. 56. Schematic Diagram of Artificial Cable of Fig. 55

necessity for maintaining this type of artificial cable at a constant temperature than with a properly constructed "lumped" type because of the great variation of the resistance of the tinfoil conductor with temperature. Each box contains a capacity of 21 microfarads, divided into seven sections of 3 microfarads each, Fig. 56, and has approximately the proper amount of resistance associated with the capacity to imitate the particular cable for which it is designed. In order to make possible a more accurate adjustment, the first box is sometimes divided into ½-microfarad sections. Even these steps are too large for close adjustment by the method outlined, and the adjustment has to be obtained by other means.

It was with an artificial cable of this type that Muirhead and Taylor in 1878 for the first time successfully duplexed a long Atlantic cable. A considerable number of artificial cables of this type are still in use.

Fig. 57. Box of Artificial Cable, Dearlove Type, for Head of Line. Earth Connection Brought Out for Each Microfarad of Capacity

33. Dearlove Type of Artificial Cable. The most recent type of artificial cable, manufactured by the Telegraph Condenser Company of London according to the Dearlove patents, is of the

"lumped" variety. The lumps of capacity are about $\frac{1}{15}$ microfarad each, but the construction is such that the lumps of capacity and resistance are not individually adjustable.

Design for Head of Line. At the first part of the artificial cable the terminals are brought out for each microfarad of

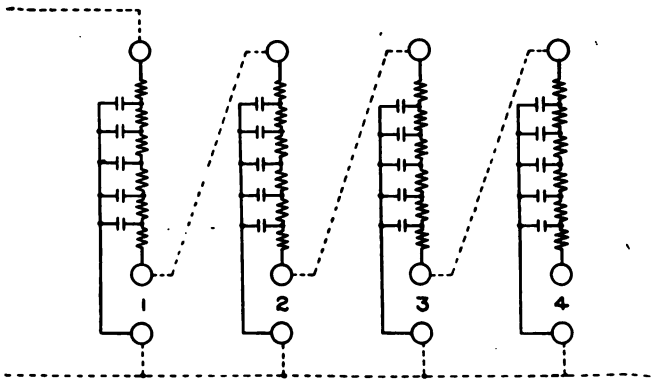


Fig. 58. Schematic Diagram of the Connections in the Box Shown in Fig. 57

capacity and a capacity of 10 microfarads is put in the first box, Fig. 57. The electrical connections of this cable are shown in Fig. 58, each section being represented by way of illustration only, as made up of five lumps, instead of the fifteen or twenty per microfarad actually used. This method of building an artificial cable permits the use of wire with a low temperature coefficient for the resistance and also of a high grade of condensers.

Fig. 59. Box of Artificial Cable to be Located near Head of Line. Earth Connections Brought Out for Each 3 Microfarads of Capacity

It is possible to secure very accurately a predetermined ratio of resistance to capacity, since the individual blocks of resistance and capacity can be adjusted before finally sealing the cable. As the many connections are of a permanent kind and well insulated

and each box hermetically sealed, the cable is free from the variation of contact resistance and many of the insulation difficul-

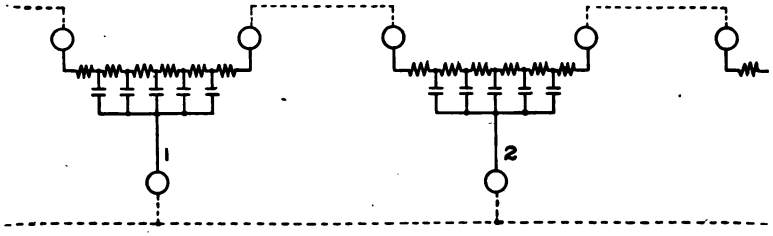


Fig. 60. Schematic Diagram of Connections in Box Shown in Fig. 59

ties of the "lumped" artificial cable of the Stearns type. Owing to the inaccessibility of the individual units of capacity and resistance, the ratio of capacity to resistance can be changed

Fig. 61. Box of Artificial Cable for Latter Part of Line. Conductor Continuous, with Taps at End of Each 3-Microfarad Section

only in the same crude manner as with the Muirhead *inductive resistance* cable, which is the chief disadvantage of this type of artificial cable.

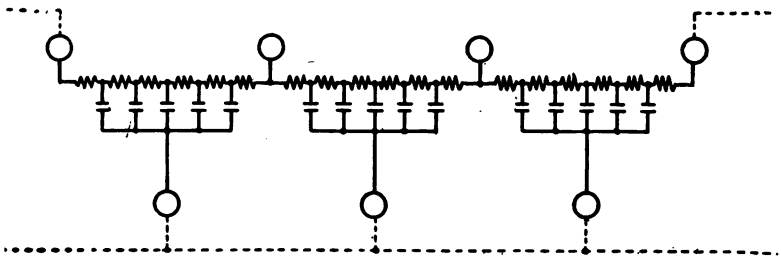


Fig. 62. Schematic Diagram of Connections in Box Shown in Fig. 61

Design for Boxes for Other Parts of Line. In the second and a number of the following boxes the connections are brought out

for each 3 microfarads of capacity, as shown in Figs. 59 and 60, since the adjustment of this part of the cable does not need to be as accurate as that of the first part. The latter part of the artificial cable has the conductor continuous, with only the taps brought out for each 3-microfarad section, Figs. 61 and 62. When completed, these artificial cables are tested with 500 volts and the insulation, which is usually about 10,000 megohms per microfarad, is measured.

The dimensions of each of the boxes shown in Figs. 55 to 62 inclusive are about 22 by 24 by 6 inches, and the weight is about 75 pounds. The large size of the boxes is due to the construction of the condensers, which is such as to minimize their variation in capacity with any change in temperature of the surrounding air. As it would require about twenty-five such boxes to duplex a cable having a capacity of 500 microfarads, the space required would be about 50 cubic feet.

In order to more adequately protect the artificial cables against variation in temperature, they are usually placed in refrigerator cabinets located in a room with special heat-insulating walls.

INSTALLATION AND ADJUSTMENT OF ARTIFICIAL CABLES

34. Difficulties with Artificial Cables. Owing to the wide difference in the capacity and the resistance per nautical mile of various ocean cables the artificial cable for duplexing is always built to suit the capacity and the resistance of each particular cable. An artificial cable, however, cannot be manufactured so as to be exactly equivalent to the real cable as laid, partly because of the variations in the cable during manufacture and partly because of the changes in the capacity depending on the pressure to which it is subjected under water. Furthermore, the capacity and the resistance of an ocean cable do not remain constant with the changing temperature of the sea water and consequently adjustments of the artificial cable have to be made.

35. Balancing Process. Since the types of artificial cables in general use—Muirhead and Dearlove—are not capable of being adjusted with accuracy, various additional devices must be used to make it possible to reduce the home-battery current in the bridge (bridge duplex is the principal type of duplex used today) to a

negligible amount. This process is known as *balancing* and is carried out by the *cut and try* method. Each person engaged in this work has his own method of procedure and a working balance on a certain cable might be obtained by different persons with quite different combinations of shunts and leaks.

For example, the method of procedure may be somewhat as follows:

Studying Original Deflection. Having connected up the artificial line normally, without any shunts or leaks, connect it to the proper place on the duplex set, using two approximately equal block condensers *A* and *B*, Fig. 63, to form the bridge arms. Put a very low resistance shunt around the recorder coil (only a few ohms at first), and depress one of the keys. There should be no signals coming in from the distant end when balancing, so that the normal ink line on the tape will be a straight line. Then any deflection of this line will be due to out-of-balance current from the home battery which it is desired to entirely eliminate. If signals were being received from the distant end, it would be difficult to distinguish the shape of the disturbance due to imperfect balance, which would be superposed on the received signals. If only a small deflection is produced, increase the shunt until a fair-sized deflection is secured and note its shape. It is from the shape of the deflection produced by the *unbalance* current that the kind of change necessary in the artificial line is determined. If the largest part of the deflection is very sharp, occurring just after closing the key, the fore part of the artificial cable should be adjusted first. These sharp deflections are known as *jar* deflections in distinction to the slow sinusoidal deflections which are known as *roll* deflections. The earth wire may be removed from one earth terminal at a time in the first part of the cable, thus removing a small amount of capacity each time and noting its effect. Any change which reduces the unbalance deflection is allowed to remain for the time being, although it may be necessary to replace it again before the final balance is secured. If no benefit is observed or if the maximum benefit possible from this procedure has been secured, it may be well to try short-circuiting various sections of the artificial conductor, one section at a time. It will usually be possible to reduce the unbalance somewhat by one or both of these methods.

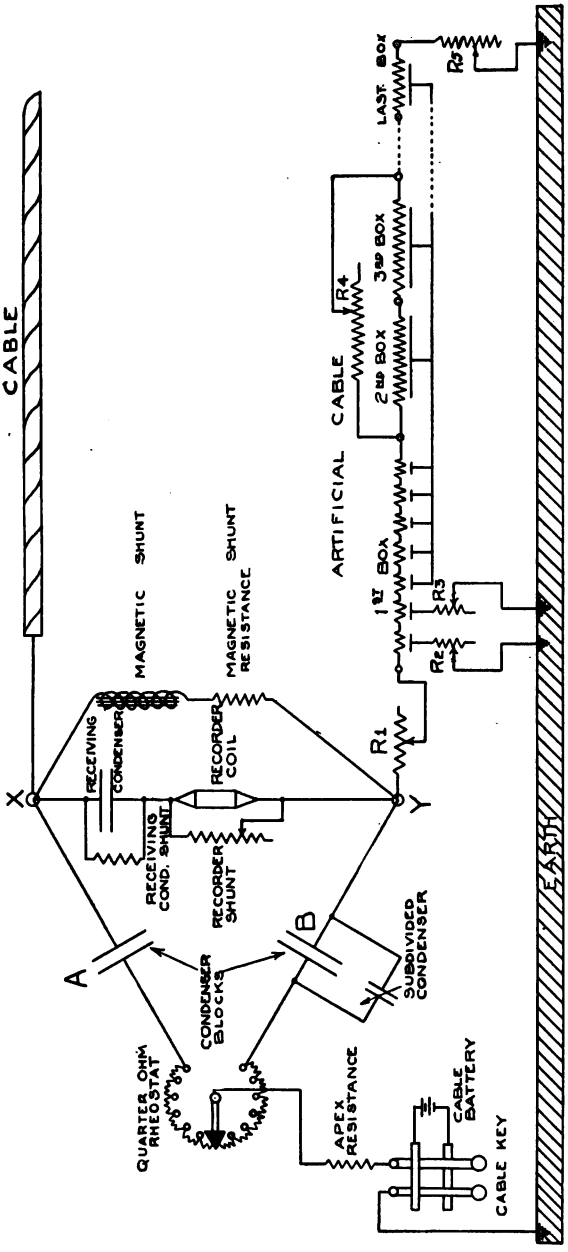


Fig. 63. Schematic Diagram of Muirhead Double Block Bridge Duplex Showing Various Circuit Arrangements Employed for Balancing

Use of Auxiliary Resistances. It will usually be necessary to place one or more separate resistances, as R_2 and R_3, Fig. 63, between the capacity and earth of the first few sections of the cable to aid in eliminating the sharp jar deflection which may occur just after closing the key. A resistance R_1, Fig. 63, at the head of the artificial cable is also necessary to aid in removing a jar deflection having slightly different characteristics.

Use of Variable Condensers. In order to correct for any change in the capacity of the ratio arms (block condensers) and to take care of certain types of jar unbalance, a small variable condenser known as the *subdivided condenser* is connected in parallel with the block condenser on the artificial line side.

Use of Quarter-Ohm Rheostat. There is still another piece of apparatus, known as the *quarter-ohm rheostat,* used in reducing unbalance deflections which come under the class of jar deflections. This rheostat, Fig. 63, is connected at the apex of the bridge so that part of it is in series with one bridge arm and the remainder in series with the other bridge arm (block condenser). As used in ordinary recorder working, there are forty steps of $\frac{1}{4}$ ohm each, but with more sensitive receiving instruments these steps must be made much smaller. It will be seen that moving the radial arm cuts resistance out of one arm of the bridge and puts an equal amount into the other arm.

These various devices are adjusted until the least possible deflection is secured, after which it may be necessary to re-adjust the artificial line itself. In adjusting the artificial line it is sometimes desirable to insert resistance instead of removing capacity in order to increase the ratio of resistance to capacity at some point in the line.

Use of Leak Resistance. If at any time during the process the predominant character of the deflection is a more or less slow movement, taking place at a longer interval after depressing the key, the trouble must be looked for farther down in the artificial cable and the methods outlined before may be used. If there is still a long slow deflection known as a roll, it may be necessary to put a resistance *leak,* as R_5, Fig. 63, from the conductor to earth at or near the end of the cable. If the insulation of the real cable is high, the low capacity of the artificial cable makes the

use of this leak resistance necessary. On account of the expense it has been the usual practice to make the artificial cables with less capacity (and less resistance) than the real cable and to use a resistance, as R_5, Fig. 63, to imitate the last part of the cable. The result, even after R_5 is adjusted to its best value, is a slow out-of-balance deflection, which in practice is reduced to a small size because the magnetic shunt around the recorder offers such a low impedance to this slowly varying current. While the legibility of the signals received on a siphon recorder is not affected by the resulting slight displacement of the siphon, a cable relay is more easily affected by the slight biasing of its moving element and therefore the artificial line has to be built out more completely. It has been customary to use an artificial cable having from 70 to 90 per cent as much capacity as the imitated real cable when using siphon recorders. Sometimes a shunt resistance, as R_4, Fig. 63, around the last part of the cable will be an aid, although this will usually be of more service in reducing that class of unbalance which shows itself in a deflection somewhere between a jar and a roll and it is also more usually applied around an intermediate section of artificial cable. The length of cable it should shunt and where it should be placed is all a matter of trial. As the balance is improved the shunt around the recorder coil is gradually decreased until there is no shunt at all around it during the last stages of adjustment. To simulate the relatively greater *absorption* in the gutta-percha dielectric, it may be necessary to use some additional capacity, with a very high resistance in series with it, in parallel with the ordinary capacity from conductor to earth.

The procedure is not generally so straightforward as described. For example, in trying to take out a *rolling* deflection the bringing in of a *jar* is often found unavoidable, and vice versa; and then the balancing for the deflection of the opposite character must be done all over again. In this way it has sometimes taken weeks of labor to get a working balance. The out-of-balance condition resulting in a jar is brought out most prominently in various ways, depending upon the exact lag after closing the key and upon the direction of the pulses of the unbalance current.

Correcting Unbalance by Interpreting Deflection. Sometimes the greatest deflection is produced by a rather slow tapping on one

key (sending current of one direction), at other times by a rapid tapping on one key, and at still other times by tapping alternately on the two keys (sending alternating current) at some given fre-

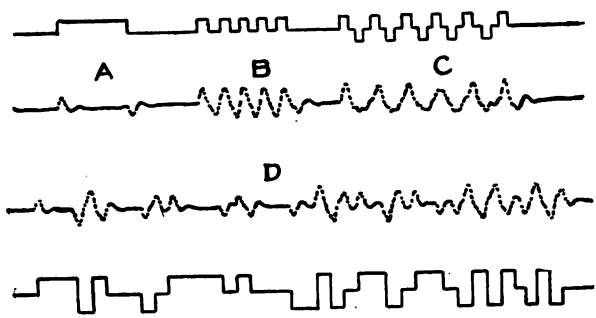


Fig. 64. Effect on Balance of Removing 1 Microfarad about Twenty Miles from Head of Artificial Cable

quency. A person experienced in balancing can tell from these various symptoms the kind of change necessary to secure a better balance. This method is often more effective than watching the results of a single closing of a key, for the out-of-balance current

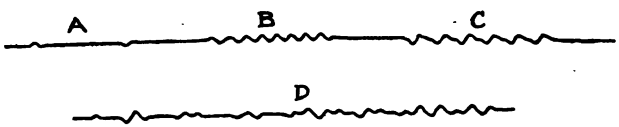


Fig. 65. Effect of Inserting 200 Ohms in Series with Conductor about Two Hundred Miles from Head of Artificial Cable

may be a rapidly alternating one, which does not show up well on one closing of the key because of the inertia of the recorder coil but can be brought out by successive impulses timed rightly. Of course, it is necessary to balance for these effects, since in practice

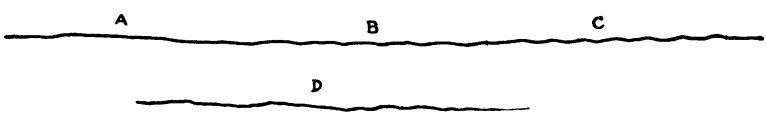


Fig. 66. Rolling Deflection Due to Leak to Earth about the Middle of Artificial Cable

pulses of one polarity and reversals follow each other at all sorts of intervals.

36. Examples of Unbalance Conditions. In a discussion of this length a comprehensive survey of all the conditions met with

in balancing could not be made as they are almost without limit, but a few examples will be given. After a balance was secured on a certain cable of such degree of accuracy that no movement of

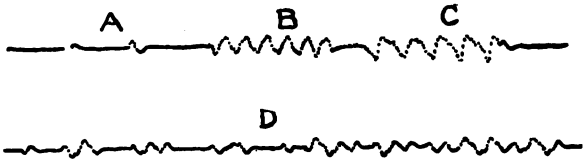


Fig. 67. Effect of Varying Value of Resistance R_1 by 2 Ohms

the siphon was noticeable, an out-of-balance condition was created in various ways with the results shown in Figs. 64, 65, 66, 67, 68, 69, and 70. While making these records no signals were being received from the distant end, so that the siphon record was normally a straight line, as the balance was originally so perfect that the outgoing signals did not cause any current to flow through the siphon recorder located in the diagonal of the Wheatstone bridge.

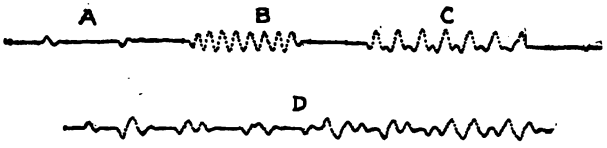


Fig. 68. Effect of Changing Capacity of Subdivided Condenser by .3 Microfarad

It is customary, as previously stated, to stop the distant end from sending when trying to correct any considerable balance trouble as the shape of the deflection can then be observed.

In Figs. 64, 65, 66, 67, 68, 69, and 70 the deflections are records of the out-of-balance disturbance only, produced by the outgoing signals, when no signals are being received. The rec-

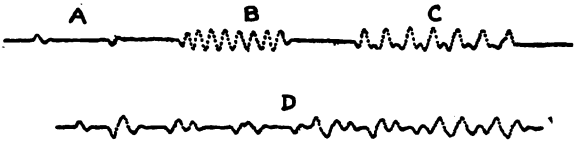


Fig. 69. Effect of Varying Quarter-Ohm Rheostat by 2 Ohms

tangular tracing at the top of the siphon record in Fig. 64 is a record on a small scale of the voltage applied to the cable to send out the signals, the disturbance from which caused the deflections

A, *B*, and *C* on the siphon record. The disturbance shown by the deflections of the siphon record marked *D* were produced by applying to the cable a signaling voltage shown by the lower rectangular tracing. These rectangular tracings were omitted from the remaining figures of the series, but the same rectangular voltage tracings apply to each of these figures. In making these records of balance disturbance, in order to secure a better illustration, the balance was thrown out to a greater extent than would have been possible in practice. It will be seen that any of these disturbance deflections superposed on, say, the signals of curve *G* of Fig. 74 would have made those signals unreadable. No illustration of signals distorted by balance disturbance is given. Signals not distorted by balance are shown in curves *C* and *G* of Figs. 74 and 76 and in other figures.

Each figure in the series under consideration consists of four sections labelled *A*, *B*, *C*, and *D*. *A* is the result of a rather pro-

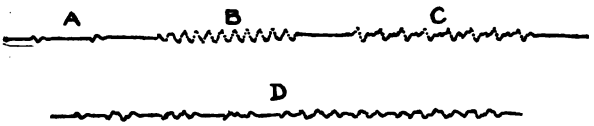


Fig. 70. Effect of Removing 100,000 Ohm Shunt around First One-Third of Artificial Cable

longed depression of a key; *B*, the result of tapping on one key (sending dots); *C*, the result of tapping alternately on both keys (sending reversals); and *D*, the result of sending the words **SN The Quick.** In Fig. 64 is shown the effect of removing 1 microfarad about 20 miles from the beginning of the artificial cable. In Fig. 65 is shown the effect of adding 200 ohms in series with the conductor at a point 2000 ohms, or approximately 200 miles from the head of the artificial cable.

The deflection resulting from placing a leak from conductor to earth at the middle of the artificial cable is illustrated in Fig. 66. The dots and reversals in Fig. 66 were sent at about one-third the speed used in Figs. 64 and 65.

In Fig. 67 we see the result of varying the resistance R_1 by 2 ohms, and in Fig 68 is shown the result of varying the subdivided condenser by 0.3 microfarad. The difference between the results of these two changes should be noted, as varying the resistance

R_1 and varying the subdivided condenser are the means most frequently used to correct for the small changes in balance which occur from day to day.

In Fig. 69 is given the type of jar deflection resulting from varying the quarter-ohm rheostat by 2 ohms.

When a 100,000-ohm shunt around the first one-third of the artificial line was removed, the unbalance deflection shown in Fig. 70 resulted.

37. Balancing Troubles. It may seem that there are an unnecessary number of methods of adjusting for the jar type of deflection but it has been found that all are necessary, as each has a somewhat different effect. Frequently, after a fairly good balance has been secured by adjusting R_1 and the subdivided condenser, it is possible to make the balance still better by changing the quarter-ohm rheostat and then readjusting R_1 and the sub-divided condenser. For recorder working the smallest steps in the resistance R_1 and the subdivided condenser are 0.1 ohm and 0.01 microfarad, respectively, and, for use with more sensitive receiving apparatus the smallest steps are 0.01 ohm and 0.001 microfarad, respectively.

Periodic Balancing. The quarter-ohm rheostat, subdivided condenser, resistance R_1, and the shunt resistance R_4, are usually mounted in a cabinet close to the siphon recorder so that the effect of changing any one of the devices may immediately be noted, as they are often adjusted without stopping traffic on the cable. They are used to balance those slight changes which take place from day to day in either the artificial cable itself or in the first part of the real cable, which may be in shallow water near the shore and may run from there to the cable station in a trench and which is therefore subject to daily changes of temperature. Where temperature changes between summer and winter are great, it is usually necessary to adjust the artificial cable itself twice a year. In repairing a cable it is frequently necessary to insert a considerable length of new cable; when this is of a different type from the original cable, the artificial cable should be changed at the proper place to compensate for the change in the real cable. The four main classes of balancing are, therefore: the original balancing of the cable; the seasonal balancing; the daily balancing; and the balancing required due to the repair of the cable.

Use of Apex Resistance Causes Retardation. Since much duplex trouble arises from the jar type of deflection, the insertion of considerable apex resistance, Fig. 63, has sometimes been resorted to. This slows down the rate of charge and discharge of the cable and consequently minimizes the effect of slight differences between the first part of the real and the artificial cables. But it also acts as an additional retardation for the outgoing signals, causing some reduction in the working speed and, therefore, should not be used except as a temporary expedient. The quarter-ohm rheostat introduces a small resistance at the apex. It is for the reason stated on page 64 that it is less difficult to balance

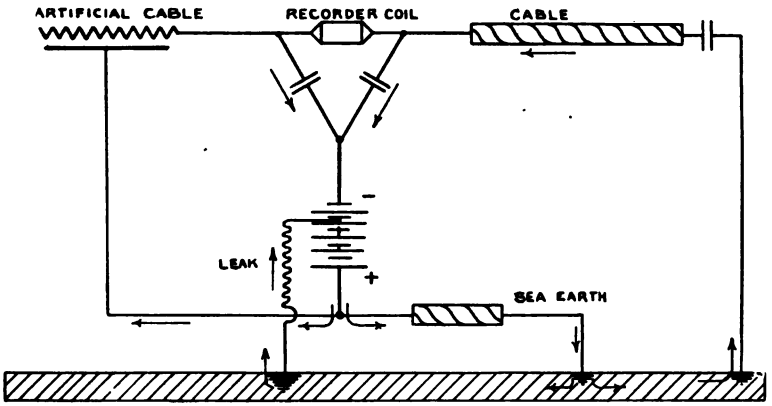


Fig. 71. Flow of Current from Leaky Battery with Negative Pole of Battery to Cable

cables having a high ratio of resistance to capacity than those in which this ratio is small.

Balance on Dot Key and Unbalance on Dash Key. A type of balance trouble entirely different from those previously described is that in which the cable is found to be balanced when tapping on, say, the dot key (positive pole of the battery to cable) but is not balanced when tapping on the dash key (negative pole of the battery to cable), and vice versa. This may be due either to a poorly insulated cable battery or to a high resistance fault in the cable. Whenever other near-by electrical circuits, either power or telegraph, are likely to cause the potential of the earth at the cable station to vary, it is customary to take the earth connection of each cable some distance out to sea. This is spoken of as the

sea-earth. With such an arrangement one way in which a leak on the cable battery could cause the balance to vary with the polarity of the battery to cable is shown in Figs. 71 and 72. The leak, represented as being near the negative end of the battery, does not affect the current in the artificial line. When the negative pole of the battery is to cable, the current into the real cable is less than normal, and vice versa.

Handling Cable Battery Leak. When there is only a slight fault in a cable, no decrease in the received current may be noticed but the duplex balance is liable to be affected. If the potential of the conductor with respect to the earth at the leak is

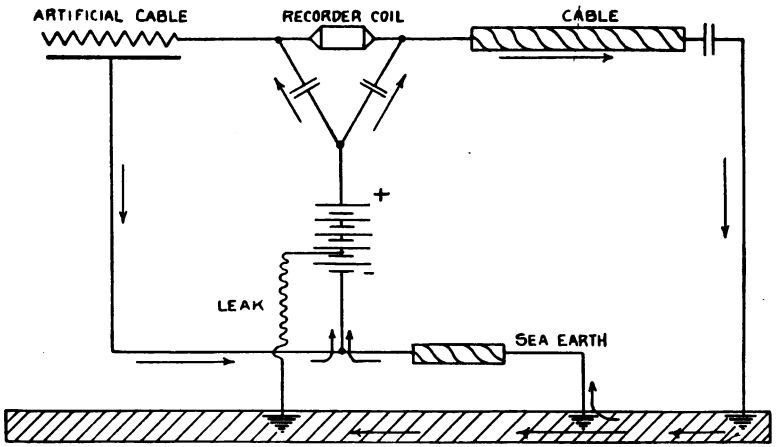


Fig. 72. Diagram Indicating Flow of Current from Battery Shown in Fig. 71 with Positive Pole of Battery to Cable

positive for some time, the current flowing will decompose the water with an accompanying accumulation of oxygen around the leak, producing polarization; it will also cause the formation of copper chloride on the exposed copper conductor. The oxygen bubbles and the copper chloride produced by the action of the current both tend to increase the electrical resistance of the leak and may even practically stop the flow of current. If the potential of the conductor is then made negative with respect to the earth, the copper chloride and oxygen bubbles will be removed and the resistance of the leak decreased. Thus the duplex balance would vary from time to time, depending on the potential of the

conductor at the leak, and duplex operation would be very unsatisfactory, or even impossible. It may be possible to maintain duplex operation by the use of what is known as a *sealing* battery. This is an auxiliary battery connected to the cable in such a way that the cable conductor at the leak will always be positive with respect to the earth and thus increase the resistance of the leak, or *seal* it. The positive pole of the sealing battery is connected to the cable, and the voltage used must be greater than the greatest negative potential that would normally exist at the leak in order that the potential at the leak may never fall below the earth potential. Thus, if the leak is near the sending end of the cable,

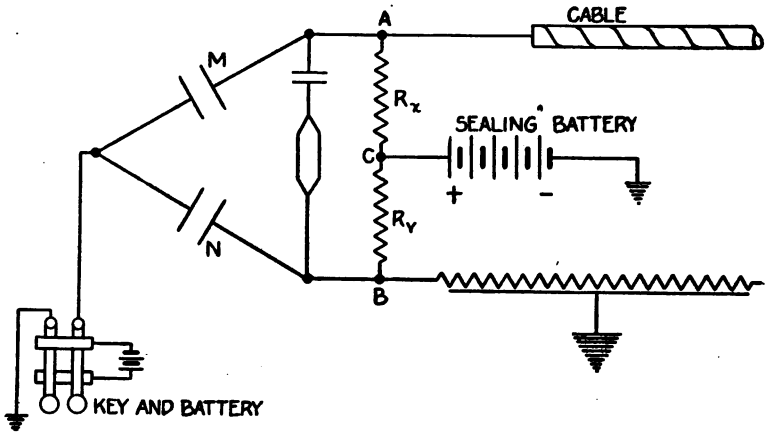


Fig. 73. Method of Applying Sealing Battery to Leaky Cable

the voltage of the sealing battery would have to be larger than if the leak were toward the middle of the cable, because the potentials due to the signals are greater near the sending end. One method of applying a sealing battery with duplex connections is shown in Fig. 73. The resistances R_x and R_y should be very large so that only a small part of the outgoing and incoming current will be *drained off;* furthermore, either R_x or R_y should be adjustable so that a point C may be found to which an earth connection can be made without necessitating a great change from the normal balancing conditions. When the cable is balanced, points A and B are at the same potential with respect to the earth, and if the blocks M and N are exactly equal, the use of

equal resistances R_x and R_y will produce the same change in potential at A and B, leaving these points at the same potential and the balance undisturbed.

If the blocks M and N are not exactly equal, the resistances R_x and R_y will need to have a ratio different from unity, and it may be necessary to make some slight changes in the artificial cable to get the best balance. In cases where the resistance of the leak is so low as to reduce the size of the signals at normal speed until they are scarcely visible, necessitating a great reduction in speed, a sealing battery may increase the resistance of the leak sufficiently to make it necessary to reduce the speed only slightly or not at all. In such cases the resistance of the leak might not be constant enough to work duplex and a simplex connection would be used.

Perfect Balance Not Obtainable. The balances obtained by the methods outlined in sections **35, 36,** and **37** could not be perfect since the exact similarity between the artificial-cable circuit and the main-cable circuit is destroyed by the use of the shunts, leaks, etc. However, these various expedients usually enable one to make the characteristics of the artificial-line circuit such that, when the key is depressed, the main- and artificial-line currents will be equal at a sufficient number of points that any differences at other points will not be large enough to disturb a siphon recorder. With magnifiers in the receiving circuit it is not always possible to secure a sufficiently close balance to be able to use the full magnification of these instruments.

It has been proposed to use a sinusoidal-shaped pulse instead of the present type of rectangular-shaped pulse in the forming of dots and dashes, since the more gradual increase in the applied voltage with such a pulse would cause less disturbance to the duplex balance than the sudden increase in applied voltage does in the present method of transmission. Or, the higher frequency components of the signals, for which a balance must be obtained, are of less magnitude when the signals are made up of sinusoidal elements than when they are made up of rectangular elements.

It must not be overlooked that while it is difficult to obtain a balance originally it is also very difficult to maintain a balance with the present methods of balancing.

38. Duplex Transmission. In the previous general discussion of transmission it was stated that the higher the frequency of the current sent into the cable the greater the attenuation it suffered in transmission. As the ordinary cable signals are made up of currents of a number of different frequencies and as the received signals are interpreted by their size (height) and shape it is necessary to eliminate their lower frequency components or they may distort the received signal beyond recognition. The ideal signal is one that rises rapidly to its maximum height, remains at that height for the duration of the signal, and then decreases rapidly to zero. If the applied voltage were plotted as a curve, it would have the shape shown in curve *A*, Fig. 74. To secure arrival curves of signals of the same shape, the circuit must transmit currents of all frequencies equally well or, failing in this, the currents of lower frequencies must be reduced approximately in proportion to their excess in size over that of the current of the fundamental dot signals. The fundamental dot frequency is the highest frequency current necessary to be received. As the principles underlying the general methods of *shaping* the received signals have been stated, the particular methods of applying these principles in duplex operation will now be considered.

Use of Receiving Condensers. In the Muirhead double-block bridge duplex, which is the modern method of duplexing, the block condensers at each end of the circuit tend to equalize the currents of various frequencies by offering an impedance which varies inversely as the frequency of the currents, that is, the lower the frequency the higher the impedance. It was early found that the shape of the signals could be improved by the use of an additional condenser, called the receiving condenser, in series with the receiving instrument in the bridge, as shown in Figs. 63 and 75. There is no fixed rule governing the size of these condensers, but it is usual for each block condenser and the receiving condenser to have a capacity about one-tenth as large as the total capacity of the cable, although they may have a capacity from one-half to double this amount.

Methods of Shaping Signals. The curves in Figs. 74 and 76 indicate the effectiveness of different ways of shaping signals which have been received with different arrangements of receiving

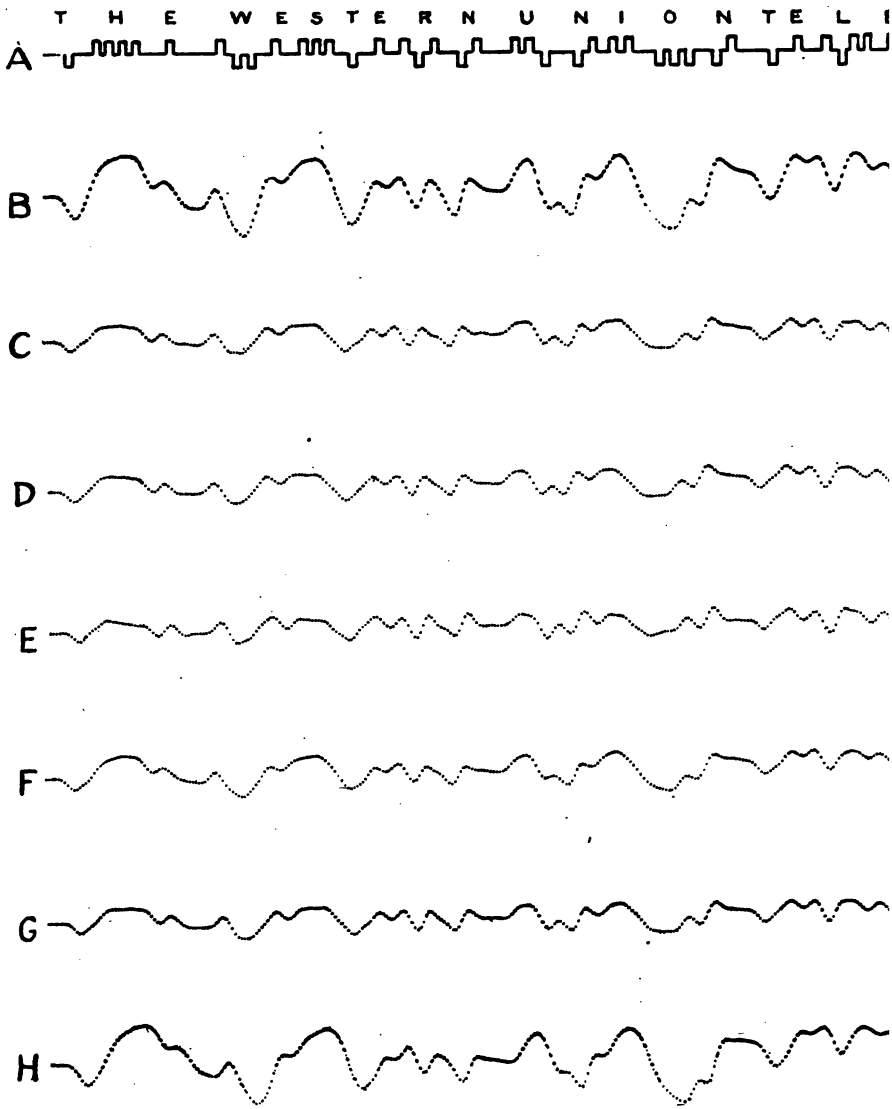
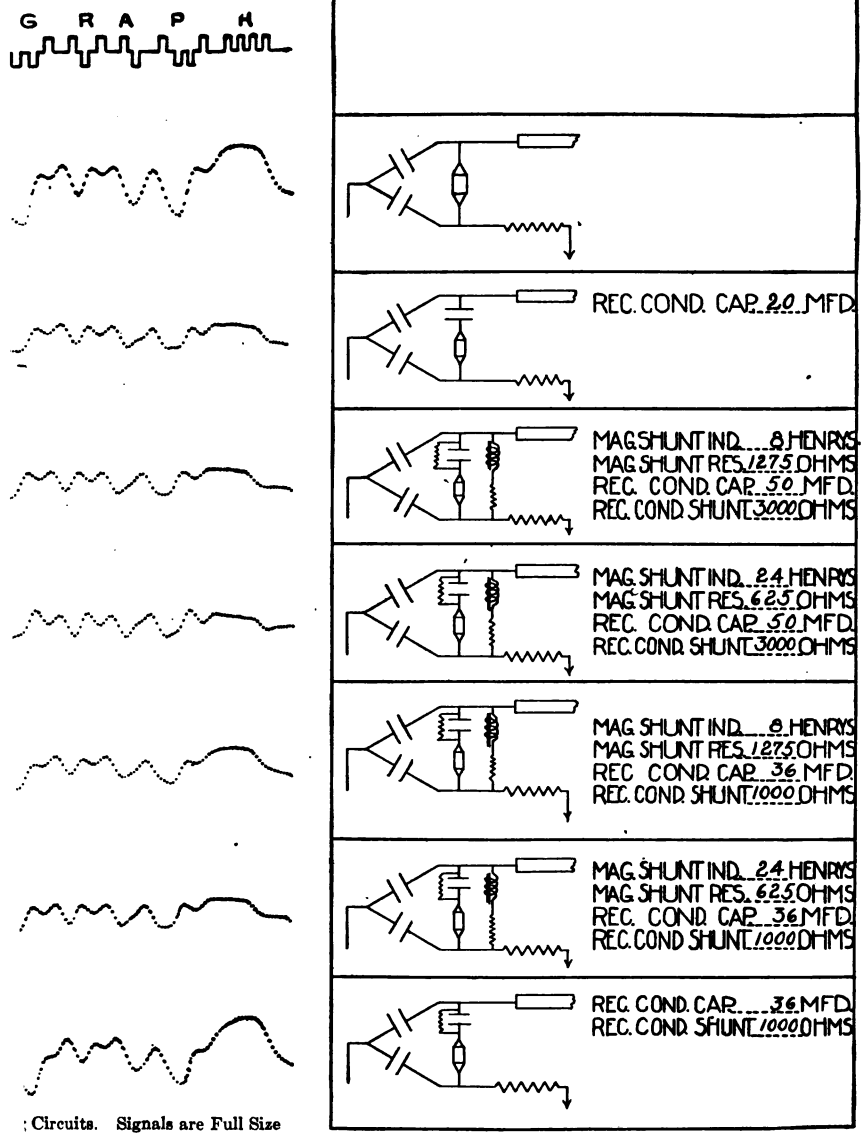


Fig. 74. Signals Received on 2.5 KR Cable at 175 Letters a Minute, with Various Types of Recei


G R A P H
REC. COND. CAP. 2.0 MFD.
MAG. SHUNT IND. 8 HENRYS
MAG. SHUNT RES. 1275 OHMS
REC. COND. CAP. 50 MFD.
REC. COND. SHUNT 3000 OHMS
MAG. SHUNT IND. 24 HENRYS
MAG. SHUNT RES. 625 OHMS
REC. COND. CAP. 50 MFD.
REC. COND. SHUNT 3000 OHMS
MAG. SHUNT IND. 8 HENRYS
MAG. SHUNT RES. 1275 OHMS
REC. COND. CAP. 36 MFD.
REC. COND. SHUNT 1000 OHMS
MAG. SHUNT IND. 24 HENRYS
MAG. SHUNT RES. 625 OHMS
REC. COND. CAP. 36 MFD.
REC. COND. SHUNT 1000 OHMS
REC. COND. CAP. 36 MFD.
REC. COND. SHUNT 1000 OHMS

; Circuits. Signals are Full Size

apparatus over a cable, the resistance and capacity of which are 5000 ohms and 500 microfarads, respectively. In recording these signals the block condensers had a capacity of 50 microfarads unless otherwise stated and the voltage of the cable battery was 50 volts. The signals were sent with 70 per cent marking and 30 per cent grounding of the sending voltage, as shown in curve *A*.

The receiving instrument was a Muirhead siphon recorder (see Fig. 94), the coil of which had a resistance of 500 ohms. Up to a certain limit the legibility or illegibility of signals is a matter of experience, some operators being able to read correctly signals that others cannot read. The signals are given at two speeds in order to show how their shape, and therefore their legi-

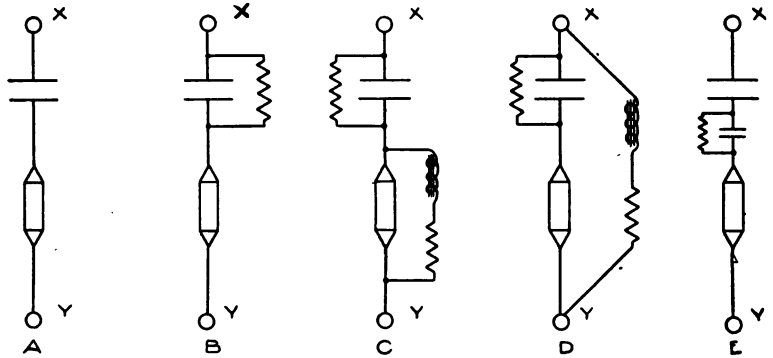


Fig. 75. Various Receiving Circuit Arrangements Used with Bridge Duplex System. Circuit from x to y is Diagonal of Bridge as Shown in Fig. 63

bility, varies with the speed. Those of Fig. 74 were received at a speed of 175 letters per minute and those of Fig. 76 at a speed of 205 letters per minute.

Curve *B*, Fig. 74, represents the signals received over this cable with the recorder coil connected directly across the block condensers. Curve *C* shows the improvement effected by the use of an unshunted 20-microfarad receiving condenser and the reduction of the block condensers to 40 microfarads each. This was the type of receiving connections used for a number of years until Mr. S. G. Brown introduced the use of magnetic shunts. These shunts are coils having a large ratio of inductance to resistance, and hence they offer a high impedance to currents of relatively

high frequency and a low impedance to currents of low frequency. They may be used to shunt the receiving instrument as at *C*, Fig. 75, or, preferably to shunt the receiving instrument and the receiving condenser at *D*. The inductance of these coils is adjustable through a wide range, and such a value is used that most of the very low frequency current is shunted around the receiving instrument. If they are used with a receiving condenser in series with the recorder coil, too much of the very low frequency current may be shunted around the receiving instrument unless a resistance shunt is placed around the receiving condenser, as at *D*, Fig. 75. This is brought out by the curve *E*, Fig. 74, for which the receiving condenser shunt was too high. The receiving condenser and magnetic shunt supplement each other in allowing the correct amount of current of each frequency to pass through the recorder coil in order to produce signals of the proper shape; that is, a greater relative discrimination can be secured in regulating the amount of current of the various frequencies by this combination than could be secured by either means alone.

Curve *D*, Fig. 74, shows the signals received when the magnetic shunt inductance had a value of 8 henrys, the resistance in series with it was 1275 ohms, and the receiving condenser and its shunt had a value of 50 microfarads and 3000 ohms, respectively.

In receiving the signals of curve *G*, Fig. 74, the inductance of the magnetic shunt was 24 henrys and its resistance 625 ohms; the capacity of the receiving condenser was 36 microfarads, and the resistance of its shunt 1000 ohms. Thus, signals similar to those of curve *D* were secured with different values of inductance, resistance, and capacity in the various parts of the receiving circuit.

Curve *E*, Fig. 74, shows the effect of altering only the magnetic shunt and its series resistance from the values used in getting curve *D* to those used in getting curve *G*. Curve *F* shows the signals received if only the receiving condenser and its shunt are so altered. It will be noticed that each of these changes has the opposite effect on the signals. Where one builds them up, the other reduces them, and the effect of both changes together, as shown in curve *G*, is to restore the signals to nearly the same shape they have in curve *D*.

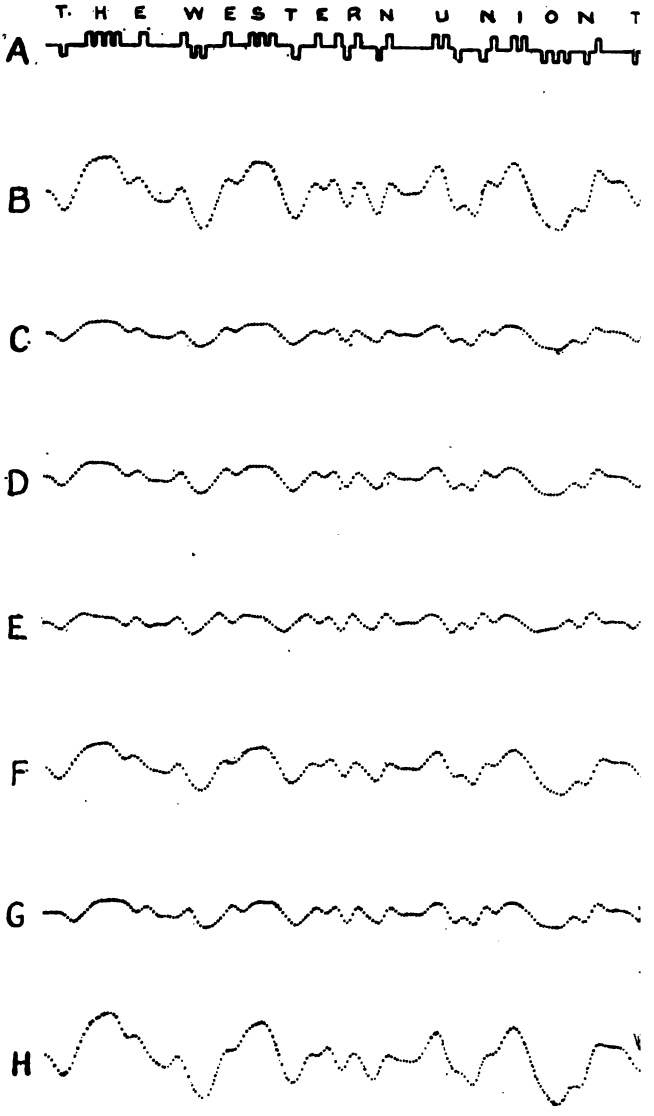
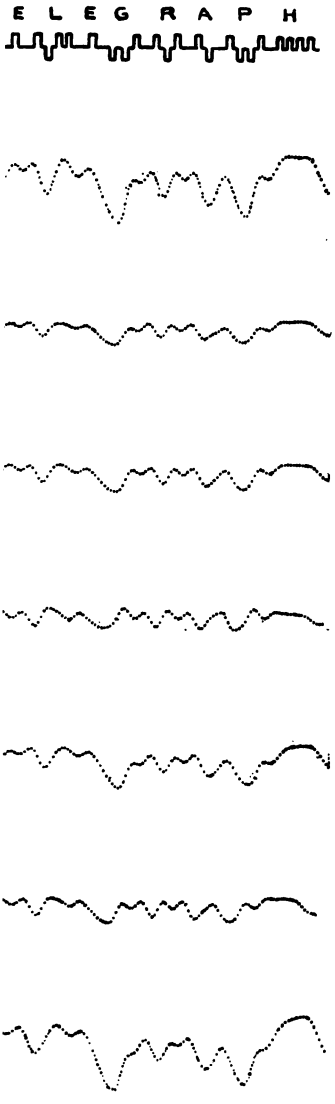


Fig. 76. Signals Received on 2.5 KR Cable, at 205 Letters a Min


E L E G R A P H
REC. COND. CAP. 20 MFD.
MAG. SHUNT IND. 20 HENRYS
MAG. SHUNT RES. 1025 OHMS
REC. COND. CAP. 50 MFD.
REC. SHUNT COND. 20000 OHMS
MAG. SHUNT IND. 20 HENRYS
MAG. SHUNT RES. 325 OHMS
REC. COND. CAP. 50 MFD.
REC. SHUNT COND. 20000 OHMS
MAG. SHUNT IND. 20 HENRYS
MAG. SHUNT RES. 1025 OHMS
REC. COND. CAP. 36 MFD.
REC. SHUNT COND. 4500 OHMS
MAG. SHUNT IND. 20 HENRYS
MAG. SHUNT RES. 325 OHMS
REC. COND CAP. 36 MFD.
REC SHUNT COND. 4500 OHMS
REC. COND. CAP. 36 MFD.
REC SHUNT COND. 4500 OHMS

with Various Types of Receiving Circuits. Signals are Full Size

The effect of removing the magnetic shunt entirely, leaving the shunted receiving condenser in circuit, is shown in curve *H*, Fig. 74. This discussion of the action of the various types of receiving circuits should be considered as more or less descriptive only, as the exact action of the various networks of circuits, in the correction of the distorted signals could be given only by a mathematical discussion too advanced for a text of this kind.

The curves at *A*, Fig. 76, correspond to those at *A*, Fig. 74, the exact values of the capacity, inductance, and resistance used at this higher speed being given for each curve in Fig. 76. The adjustment of the siphon recorder itself has a great effect on the shape of the signals, as will be explained in the discussion on receiving instruments.

Beat vs. Block Signals. It will be noticed that in the various examples of received signals so far given there are no *beat* signals—that is, signals in which a number of dots (or dashes) in sequence are separated by zero intervals. It has been found that with siphon recorder records and automatic sending when the signals are well shaped, one, two, three, four, or five dots (or dashes) that are not separated by zero intervals can be distinguished from each other by the length (duration) of the signal as easily as if each dot were separated from the adjoining ones. Signals of this type are known as *block* signals. This use of block signals permits a much higher operating speed on any given cable than would be possible if beat signals were required. This becomes evident when we observe that considerable current of higher frequency than the fundamental dot frequency (see Codes section) must be transmitted in order to produce the "valley" between dots. If the consecutive dots in a character are to be separated by a space about equal to the width of the dots themselves, 50 per cent or less marking must be used at the sending end, and a current with about double the fundamental dot frequency must be received. This is shown in Fig. 77, the two upper traces being of block signals, and the lower traces of beat signals. There is a definite limit to the frequency of the current that can be transmitted over a cable under given conditions as to applied voltage and sensitivity of receiving instrument. Consequently if the formation of the signals requires current of a higher frequency than that of the funda-

mental dot frequency, the fundamental dot frequency itself must be reduced from what it would be if there were no higher frequency currents required, as with block signals. Reduction in the frequency at which dots are sent means, of course, a corresponding decrease in the letters per minute transmitted. Signals are sometimes *sent* as block signals (100 per cent marking), particularly when they are automatically repeated from one cable into another by means of a cable relay, and are then necessarily received as block signals.

Hand-sent signals are usually received as beat signals, since their irregularity would make then difficult to read as block sig-

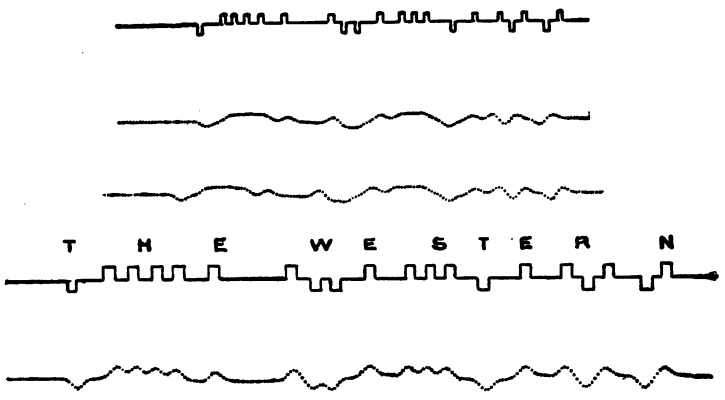


Fig. 77. Signals Transmitted with 50 Per Cent Marking and Received as "Block" Signals or "Beat" Signals According to Speed of Transmission

nals. Of course, on cables of low KR they are naturally of the beat type because of the limit in speed at which a key can be manually operated. When a mirror galvanometer is used as the receiving instrument, no permanent record is secured and the signals read from a moving beam of light must be beat signals, as the reader cannot judge accurately of their duration. Hand sending is used in this case, since the speed cannot be very great with visual signals.

39. Simplex Operation. Under most circumstances duplex operation, when receiving on siphon recorders, will permit a greater output than simplex operation, so that the latter is now used only in those rare cases where the traffic is light or when it is impossible to get or maintain a duplex balance. During the laying and

repairing of cables simplex connections are of course used in communicating between the ship and the shore.

Since the opening of the circuit at the distant end has no appreciable effect on the ordinary working current at the sending end, as shown in Fig. 50, the receiving operator cannot interrupt or *break* the sending operator. Consequently the usual method of working is to send from one station for a predetermined length of time and then to send from the other station for a certain interval. The delay due to this method produces considerable inconvenience in the handling of rush messages, such as stock quotations, etc. The inability to break the sending operator when the signals cannot be read, due to the sudden development of a fault in the sending or receiving apparatus, makes it necessary at times to repeat a large number of messages.

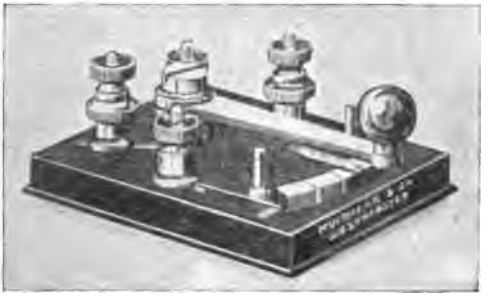


Fig. 78. "Send and Receive" Switch

It should always be possible to obtain a somewhat higher speed with simplex connections than the one-way speed with duplex connections, since only a part of the received current goes through the instrument circuit with duplex connections. It is difficult to state the exact difference in speed between simplex and duplex connections for the same reason that it is difficult, in general, to compare cable speeds. In the latter case the difficulty involves the determination of the equal legibility of signals of different shapes and sizes, or of securing signals of the same shape and size with different terminal connections. It is also to be expected that this difference in speed will depend to some extent on the KR of the cable. The simplex speed on a certain cable is 200 letters per minute, and its duplex speed in one direction is 90 per cent as great, or 180 letters per minute. Thus the gain in duplexing this circuit was 80 per cent, which may be taken as a fair figure. There are times when the greatest possible gain by duplexing is not secured because of the interference caused by an imperfect balance. This is especially the case since the introduc-

tion of magnifiers, which have proved much more sensitive than siphon recorders. In fact, at the present time the speed, when working duplex with magnifiers, is limited by the imperfection of the duplex balance, although it has not been demonstrated that the output from the increased speed secured by freedom from balance trouble when operating simplex is as great as the normal output of the cable when operating duplex.

"Send" and "Receive" Switch. When a cable is worked simplex, a switch, Fig. 78, is used for changing from sending to receiving and vice versa. The switch lever, in passing from the

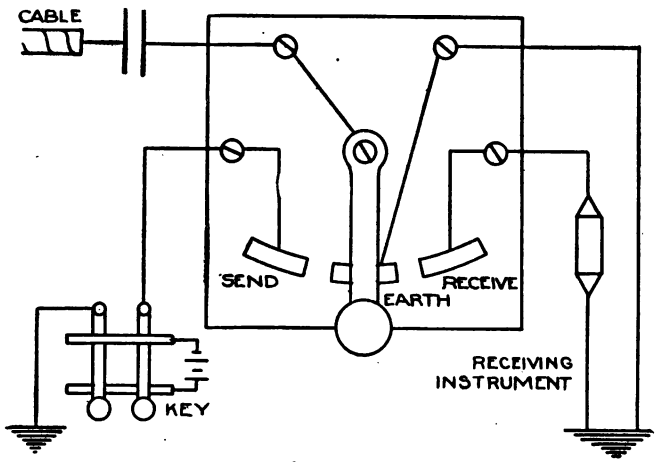


Fig. 79. Connections of "Send and Receive" Switch

sending to the receiving position, makes contact with an earthing segment, Fig. 79, thereby freeing the cable from any charge which might damage the receiving instrument if allowed to flow through it.

In the days when simplex operation was general, intermediate stations were equipped with a special commutator switch to change simultaneously from sending to receiving on one cable and from receiving to sending on the associated cable.

This was used in connection with manual translation or the *human relay* system in which messages for the next station were immediately sent on as read from the receiving instrument, thus eliminating any rewriting and a probable accumulation of messages at the intermediate station.

SUBMARINE TELEGRAPHY

PART I

Read Carefully: Place your name and full address at the head of the paper. Any cheap, light paper like the sample previously sent you may be used. Do not crowd your work, but arrange it neatly and legibly. *Do not copy the answers from the Instruction Paper; use your own words, so that we may be sure you understand the subject.*

---

1. Name four physical properties of a submarine cable.

2. Discuss the effect of temperature on insulation resistance.

3. Give your own explanation of the theory of a condenser.

4. A certain cable is 800 nautical miles long and weighs 175 pounds per nautical mile. What is the resistance at 75° F.?

5. Make a sketch showing how a magnetic shunt is connected to a cable circuit when working on duplex connections.

6. What are curbed signals?

7. Are higher voltages used for submarine cables or for land lines? Why?

8. Make a sketch showing the appearance of the received cable tape when the word "the" is received.

9. How are dot and dash signals produced?

10. What is the purpose of the quarter-ohm rheostat at the apex of the main cable circuit?

11. What is the main distinguishing feature of the Dearlove artificial cable?

12. Discuss two types of artificial cables.

13. Make a simple theoretical diagram of a Muirhead double-block bridge duplex.

14. What is the significance of the KR law?

15. What are block signals?

16. Into what four classes may balancing be divided with reference to cause for balancing?

17. Do unbalance conditions near the distant end produce rolling deflections or jar deflections? Why?

18. What is the usual approximate ratio between the total capacity of an artificial cable and the real cable with which it is used when receiving on siphon recorders?

19. Distinguish between rolling deflections and jar deflections.

20. Why should an apex resistance, other than the quarter-ohm rheostat, not be used to aid in securing a balance?

21. What is the usual insulation resistance of a new cable in megohms per microfarad?

22. What is the general effect of a slight leak in a cable?

23. Discuss two methods of shaping received signals.

24. What is a sealing battery?

25. How would you proceed to eliminate unbalance on the dash key if the dot key indicated a proper balance?

After completing the work, add and sign the following statement:
I hereby certify that the above work is entirely my own.
(Signed)

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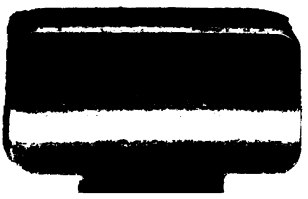
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